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MCDONNELL DOUGLAS

SPACE TUG SYSTEMS STUDY (CRYOGENIC) SEPTEMBER DATA DUMP

VOLUME 2 Summary
Program Option 2

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EPARED FOR NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MARSHALL SPACE FLIGHT CENTER
UNDER CONTRACT NO. NAS8-29677

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PREFACE

This study report for the Tug Program is submitted by the McDonnell Douglas Astronautics Company (MDAC) to the Government in partial response to Contract Number NAS8-29677.

The current results of this study contract are reported in eight volumes:

Volume 1 — Summary, Program Option 1

Volume 2 — Summary, Program Option 2

Volume 3 — Summary, Program Option 3

These three summary volumes present the highlights of the comprehensive data base generated by MDAC for evaluating each of the three program options. Ea volume summarizes the applicable option configuration definition, Tug perforn ance and capabilities, orbital and ground operations, programmatic and cost considerations, and sensitivity studies. The material contained in these th volumes is further summarized in the Data Dump Overview Briefing Manual.

Volume 4 — Mission Accomplishment. (3 Books and 1 Supplement Bound Together)

This volume contains mission accomplishment analysis for each of the three program options and includes the tug system performance, mission capture, an fleet size analysis.

Volume 5 — Systems (3 Books)

This volume presents the indepth design, analysis, trade study, and sensitiv technical data for each of the configuration options and each of the Tug sys i.e., structures, thermal, avionics, and propulsion. Interface with the Shu and Tug payloads for each of the three options is defined.

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Volume 6 – Operations (3 Books)

This volume presents the results of orbital and ground operations trades and optimization studies for each option in the form of operations descriptions, time lines, support requirements (GSE, manpower, networks, etc.), and resulta costs.

Volume 7 – Safety (3 Books)

This volume contains safety information and data for the Tug Program. Specif safety design criteria applicable to each option are determined and potential safety hazards common to all options are identified.

Volume 8 – Programmatics and Cost (3 Books)

This volume contains summary material on Tug Program manufacture, facilities, vehicle test, schedules, cost, project management, SR&T, and risk assessment f each option studied.

These volumes contain the data required for the three options which were selected by the Government for this part of the study and are defined as:

A. Option 1 is a direct development program (I.O.C.: Dec 1979). It emphasizes low DDT&E cost; the deployment requirement is 3500 pou into geosynchronous orbit, it does not have retrieval capability and it is designed for a 36-hour mission. MDAC has also prepare data for an alternative to Option 1 which deviates from certain requirements to achieve the lowest practicable DDT&E cost.

B. Option 2 is also a direct development program (I.O.C.: 1983). I emphasizes total program cost effectiveness in addition to low D cost. The deployment requirement is 3500 pounds minimum into ge chronous orbit and 3500 pounds minimum retrieval from geosynchro orbit.

C. Option 3 is a phased development program (I.O.C.: 1979 phased t I.O.C. 1983). It emphasizes minimum initial DDT&E cost and low program cost. The initial Tug capability will deploy a minimum

3500 pounds into geosynchronous orbit without retrieval capability, however, through phased development, it will acquire the added capability to retrieve 2200 pounds from geosynchronous orbit. The impact of increasing the retrieval capability to 3500 pounds is also provided.

CONTENTS

INTRODUCTION

The Government's evaluation of the MDAC Tug concept selection data and recommendations presented in July 1973 resulted in a directive to conduct further in-depth analysis and to provide the data and conclusions for three selected Cryogenic Tug program options.

The material presented in this MDAC Tug program study is completely responsive to the negotiated statement of work and subsequent direction. The study results provide a comprehensive data base that can be used in the Government planning studies to select the most attractive Cryogenic Tug program option for comparison with other alternatives under consideration. The Option 2, Direct Development Program (IOC: 1983) study results are summarized in this data package, Volume 2.

The current concept evaluation process has been conducted, and data substantiating the conclusions and recommendations reached by MDAC are provided herein. Additional substantiation and detailed supporting documentation are contained in Volume 4 - Mission Accomplishment, Volume 5 - Systems, Volume 6 - Operations, Volume 7 - Safety, and Volume 8 - Programmatics and Cost, as well as in the briefing material.

A program overview has been included in Section 1 of this volume. It contains the key results of Option 2 study and a comparison of these with results of Option 1 and Option 3.

Section 1
TUG PROGRAM

1.1 Tug Program Overview

Each of the three tug options is discussed in a separate volume dedicated to the individual option being summarized. For the convenience of the reader, this section contains a brief program overview which presents the highlight features of all three options. Comparative data should be used with the awareness that the mission model is different for each of the options.

The following figures are individually discussed in subsequent pages.

Figure 1 -1 Space Tug Operations
-2 Key Issues
-3 Space Tug Program Options
-4 Mission Model Comparison
-5 Performance Comparison
-6 Cost Comparison
-7 Space Tug Program Option Summary Comparison

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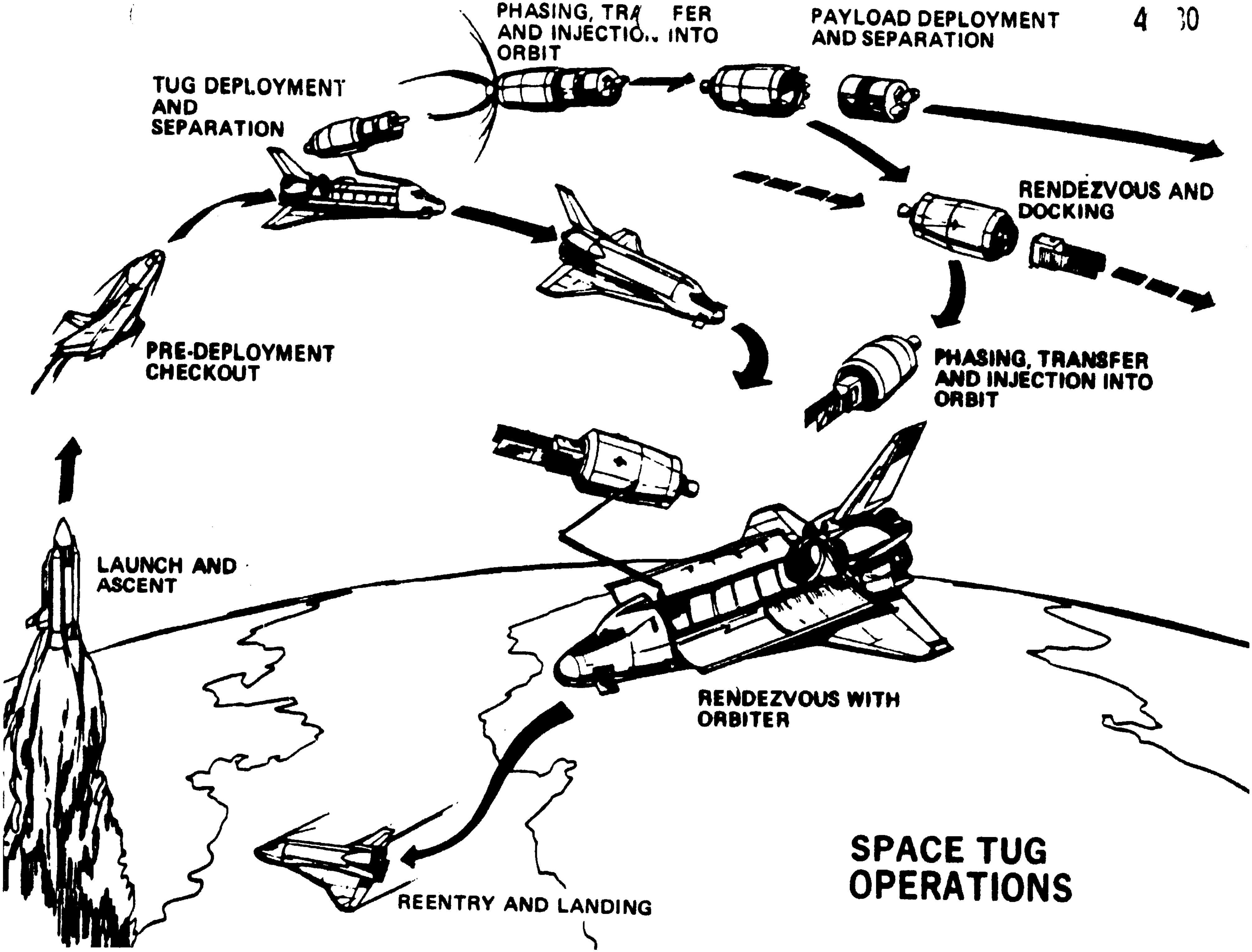
SPACE TUG OPERATIONS

This study encompasses all aspects of the Space Tug operations. Depicted on the chart is the different phases of flight operations from liftoff until landing. Included is the deployment of the Tug from the Shuttle cargo bay at 160 nmi and the rendezvous of a Tug and its retrieved payload with the Orbiter before reentry and landing. Ground operations were also studied extensively.



SPACE TUG
OPERATIONS

KEY ISSUES

Since the Tug flies with the Orbiter during ascent and return to Earth it mus meet the safety standards for a manned space vehicle during these times. For performance and capability it must at least meet the minimum requirements specified by the Government. In all operations minimum DDT&E costs are important. However, DDT&E costs should not be lowered to the point that the operations cost, for the life of the vehicle, will be prohibitive. In additi to minimum DDT&E and operations cost, low peak year funding is desirable, especially through the 1975 to 1978 time period.

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KEY ISSUES

- MEET SAFETY STANDARDS
- MEET PERFORMANCE/CAPABILITY REQUIREMENTS

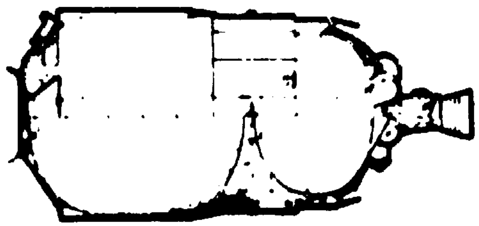
- MINIMIZE DDT&E COSTS
- MINIMIZE PEAK YEAR FUNDING
- DRIVE OPERATIONS COSTS DOWN

SPACE TUG PROGRAM OPTIONS

The three options indicated were those provided by the Government. The deployment and retrieval requirements are minimum for each option. Numerous sensitivity studies were conducted for each of the options and include varying the IOC data and assessment of program impacts.

SPACE TUG PROGRAM OPTIONS

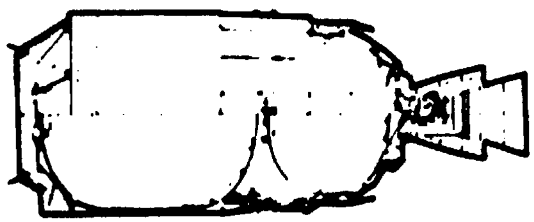
OPTION 1.
DIRECT DEVELOPMENT PROGRAM



IOC: DEC 1979

- LOW DDT&E
- DEPLOY 3500 LB (GEOSYNCHRONOUS)
- NO RETRIEVAL CAPABILITY
- 36 HOUR MISSION

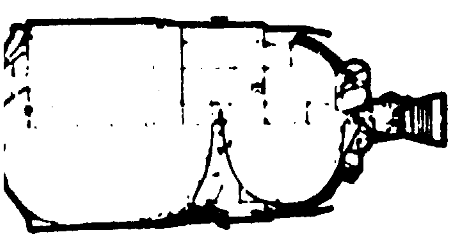
OPTION 2.
DIRECT DEVELOPMENT PROGRAM



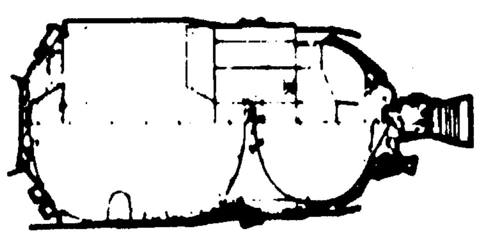
IOC: DEC 1983

- TOTAL PROGRAM COST EFFECTIVENESS
- LOW DDT&E
- DEPLOY 3500 LB (GEOSYNCHRONOUS)
- RETRIEVE 3500 LB (GEOSYNCHRONOUS)

PTION 3.
HASED DEVELOPMENT PROGRAM



IOC: DEC 1979



DEC 1983

- MINIMIZE INITIAL DDT&E
- LOW TOTAL PROGRAM COST
- INITIAL:
  DEPLOY 3500 LB (GEOSYNCHRONOUS)
  NO RETRIEVAL CAPABILITY
- FINAL:
  DEPLOY 3600 LB (GEOSYNCHRONOUS)
  RETRIEVE 2200 LB (GEOSYNCHRONOUS)

MISSION MODEL COMPARISON

The mission models provided by the Government for each option different in number and types of missions and the weights of the payloads involved. As a result of these necessary differences, care must be taken in comparing one option to another. For example, in each option, the time of operation is fr(IOC to 1990 resulting in different program durations. The mission model for Option 1 contains 360 deployment missions and 4 sortie missions over an eleve year period (1980 through 1990). The payload weights were all "current desi weights; the minimum in the total mission model. Of the total, 270 are geo-synchronous or high altitude, 22 interplanetary and 68 low orbit missions.

Option 2 has the heaviest payloads (using some of the low cost payload weigh from the total mission model) and the most missions per year however the later IOC (December 1983) results in only a seven year duration. The missio model includes retrieval missions as well as deployment missions. In additi multiple deployment missions require a positional separation of 60° between payloads whereas the Option 1 model allowed deployment of multiple payloads at one orbital location. The Option 2 model contains 437 missions (258 depl ments and 179 retrievals) of which 328 are geosynchronous or high altitude, are interplanetary and 90 are low orbit missions.

The Option 3 mission model is quite similar to the Option 2 model except for the earlier IOC (December 1979) the elimination of the retrieval mission for NASA mission 5 and its decreased weight. For the years prior to 1984 (the final configuration IOC date) the model is like the Option 1 model for those years except for the increased payload weights. Out of 558 missions (387 deployments and 171 retrievals), 430 are geosynchronous or high orbits, 22 interplanetary, and 106 low orbit missions.

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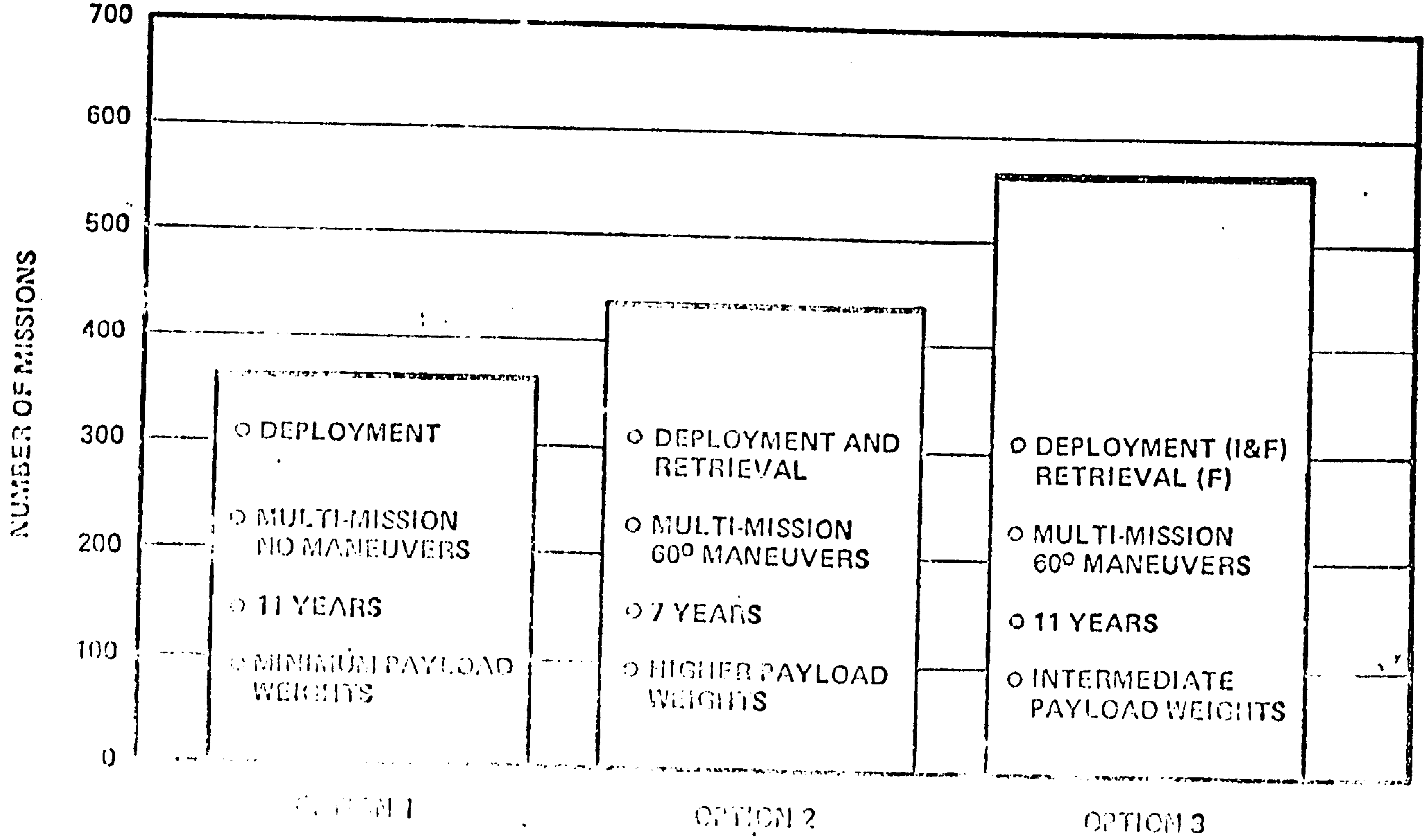
MISSION MODEL COMPARISON



OPTION COMPARISON—PERFORMANCE

This chart compares the performance of the vehicle studies for each of the three options. In the case of Option 2 it was possible to use higher technology in this vehicle because of the 1983 IOC date. Consequently, its deployment, retrieval and round trip capability far exceeds the other options. It uses a Category II RL10 engine and the other vehicles have Category I RL10 engines. The final vehicle for Option 3 could be made into a vehicle with performance similar to Option 2 if the Category II RL10 engine were used instead of the Category I. The deployment capability of the Option 3 Initial vehicle and that of Option 1 are very close.

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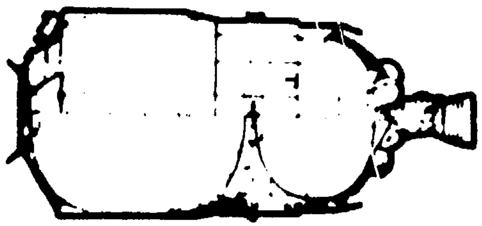
OPTION COMPA ISON

PERFORMANCE

OPTION 1
DIRECT DEVELOPMENT PROGRAM

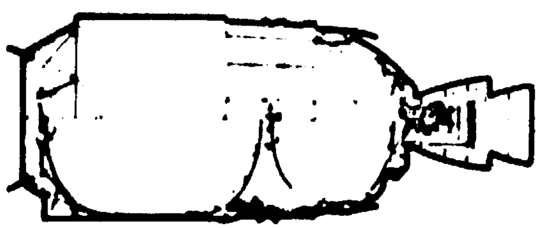


IOC: DEC 1979

- DEPLOY – 3,521
- RETRIEVE – NONE
- ROUND TRIP – 993

OPTION 2
DIRECT DEVELOPMENT PROGRAM

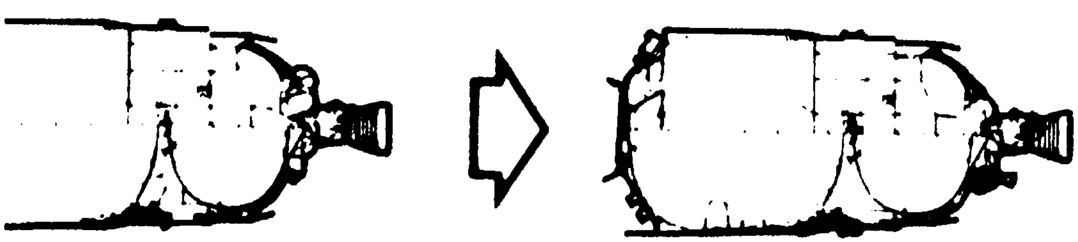
✓



IOC: DEC 1983

- DEPLOY – 7,640
- RETRIEVE – 4,814
- ROUND TRIP – 2,953

ON 3
ED DEVELOPMENT PROGRAM



DC: DEC 1979

DEC 1983

		INITIAL	FINAL
DEPLOY	–	3,588	4,330
RETRIEVE	–	NONE	2,567
ROUND TRIP	–	1,335	1,611

OPTION COMPARISON – COST

This chart provides a cost comparison breakdown of the different options. Th costs which are strongly dependent on the mission model are specifically iden tified. Since the mission model must vary between options (i.e., Retrieval vs Deploy only), care must be taken when comparing these costs.

An interesting comparison is the DDT&E cost for Option 1 and the DDT&E cos for the Initial Option 3. It should be noted that the initial phase of Option 3 is less costly than Option 1 because some of the initial GSE costs for Option 3 have been deferred to final phase. This is possible because of the limited initial fleet size. However, from a peak funding view, the initial phase of Option 3 and Option 1 are identical and peak in 1978 at 79.7 million. The total DDT&E for Option 3 is same 80 million over Option 1 which provides the required development for the required additional capabili e.g., Retrieval, 6 days, etc. The final phase of Option 3 peaks at 90.2 mil lion in 1981. The advantages of the Option 3 over Option 1 is that a phasab vehicle can be provided with no initial DDT&E penalty.

The higher Option 2 DDT&E cost is expected with this higher capability Tug. The peak year funding of Option 2 occurs in 1982 consistent with the December 1983 IOC.

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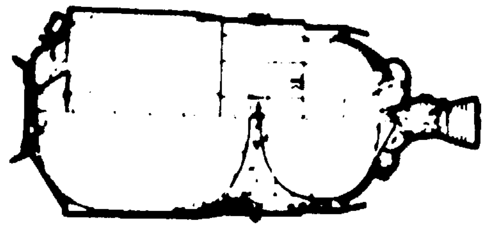
OPTION COMPARISON

COST (IN MILLIONS OF DOLLARS)

OPTION 1
DIRECT DEVELOPMENT PROGRAM

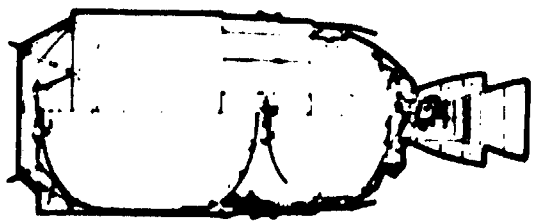


IOC: DEC 1979

• DDT&E	–	$197.1
• PEAK YEAR	–	76.7
• COST/FLT	–	0.90
• FIRST UNIT COST	–	14.4
• OPERATIONS	–	200.8
• PRODUCTIONS	–	179.6
• TOTAL PROGRAM	–	577.4

OPTION 2
DIRECT DEVELOPMENT PROGRAM

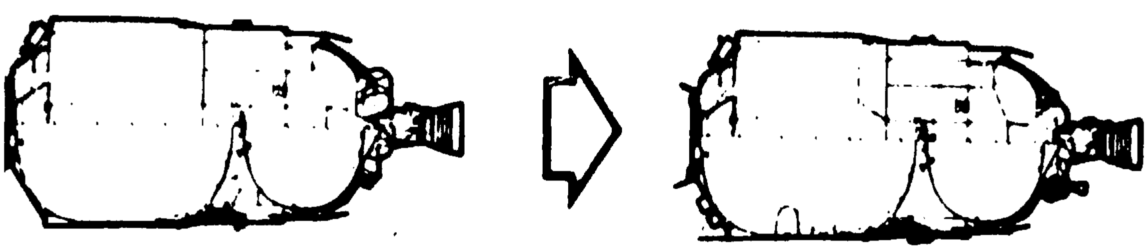
✓



IOC: DEC 1983

• DDT&E	–	$298.8
• PEAK YEAR	–	124
• COST/FLT	–	0.76
• FIRST UNIT COST	–	18.1
• OPERATIONS	–	169.4
• PRODUCTION	–	214.3
• TOTAL PROGRAM	–	682.5

OPTION 3
PHASED DEVELOPMENT PROGRAM



IOC: DEC 1979 DEC 1983

		INITIAL	FINAL
• DDT&E	–	190.1	88.8
• PEAK YEAR	–	76.7	90.2
• COST/FLT	–	1.07	0.71
• FIRST UNIT COST	–	14.7	17.4
• OPERATIONS			
• OPERATIONS	–	88.6	204.5
• PRODUCTION	–	98.6	176.8
• TOTAL PROGRAM	–	377.3	470.1

• MISSION MODEL DEPENDENT

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SPACE TUG PROGRAM OPTION SUMMARY

CONFIGURATION DATA

OPTION NO.	1	1A	2	3I	3F	3S
IN ENGINE	CAT I RL 10	CAT I RL-10	CAT 2A RL 10	CAT I RL 10	CAT I RL 10	CAT 2A RL 10
KTURE RATIO (EMR)	5.5:1	5.5:1	6:1	5.5:1	5.5:1	6:1
	441.0	441.0	450.2	441.0	441.0	450.2
RUST	15K →	→	→	→	→	→
ESSURIZATION	AMB He	AMB He	ZNPSH	AMB He	COLD HEATED He	ZNPSH
S	MONO B/D	MONO B/D	BI-PROP	MONO B/D	BI-PROP	BI-PROP
DPELLANT UTILIZATION	CLOSED LOOP →	→	→	→	→	→
EUMATIC BOTTLES	SIVB TITAN →	→	→	→	→	→
RUCTURE CONFIGURATION	LCT	LCT	LCS	LCT	LCT	LCT
ELL CONST AND MATERIAL	OPEN AL-ISO →	→	GF/AL H'COMB'	OPEN AL-ISO →	→	→
NK CONSTRUCTION	AL ISO-G	AL ISO-G		AL ISO-G	AL ISO-G	AL ISO-G
NK MATERIAL/DOME	2219 TAPER →	→	→	→	→	→
NKAGE	2219 ISU →	→	2219 MONO	2219 ISU →	→	→
SIDEWALL STRUCTURE	LATCH ONLY	EXP BOLTS	MAN ADJ	LATCH ONLY	MAN ADJ →	→
ULATION	REF →	→	MLI	REF	MLI →	→
UIP THERMAL CONT	H-PIPE PANEL →	→	→	→	→	→
RUST STRUCTURE	Ti ISO →	→	FG ISO →	→	→	→
NK SUPPORTS	Ti TUBE →	→	FG TUBE →	→	→	→
WER SYSTEM	BATT	BATT	ADV FCP	BATT	ADV FCP →	→
NDEZVOUS CONCEPT	NONE →	→	LASER	NONE	LASER →	→
IDANCE, NAV AND CONTROL	IMU ST →	→	→	→	→	→
TA MANAGEMENT	1-CENT 2 RP →	→	2-CENT	1 CENT 2 RP	2 CENT 2 RP →	→
BOARD CHECKOUT	LRU S/O →	→	→	→	→	→
TONOMY LEVEL	IV	IV	III	IV	III	III

PROGRAMMATIC DATA

OPTION NO.	1	1A	2	3I	3F	3S
DESCRIPTION	INTERIM MIN DEV	INTERIM LOW COST	DELAYED MIN DEV	PHASED INITIAL	PHASED FINAL	PHASE HI PER
IOC DATE	DEC 79	DEC 79	DEC 83	DEC 79	DEC 83	DEC 83
MULTI-MISSION CAP.	YES →	→	→	→	→	→
PL SPIN UP CAPABILITY	NO →	→	YES	NO	YES →	→
PL POWER PROVISIONS	0	0	300	0	300	300
MISSION DURATION	1 1/2 DAY	1 1/2 DAY	6 DAY	1 1/2 DAY	6 DAY	6 DAY
PAYLOAD DEP (SYNC)	3,521	2,871	7,840	3,531	4,350	8,732
PAYLOAD RET (SYNC)	-	-	4,814	-	2,455	4,136
PAYLOAD RT (SYNC)	993	870	2,953	1,325	1,827	2,638
BURNOUT WEIGHT	7,340	7,555	6,430	7,470	7,100	6,974
GROSS WEIGHT (LESS P/L)	59,334	58,549	63,120	59,335	63,120	63,100
USABLE PROPELLANT	51,342	51,342	55,932	51,212	54,881	56,027
MASS FRACTION	0.865	0.862	0.888	0.863	0.868	0.872
DDT&E $ MILLIONS	197.05	177.01	288.77	190.1	88.8	
OPERATIONS $ MILLIONS	200.01	-	180.44	88.8	204.5	
PRODUCTION $ MILLIONS	179.57	-	214.29	92.6	178.8	
TOTAL PROGRAM $ MILLIONS	577.43	-	682.50	377.3	470.1	
FLEET SIZE	13	-	12	5	11	10
PEAK FUNDING/YR $ MILLIONS	78.7/78	-	124/82	78.7/78	98.2/81	
MAIN STAGE (1ST UNIT) $ MILLIONS	14.44	-	18.88	18.83	17.4	
MAIN STAGE (AVG) $ MILLIONS	12.22	-	16.41	14.7	15.90	
KICK STAGE $ MILLIONS	2.30	-	3.07	8.15	8.91	
COST/FLT $ MILLIONS						
MODE 1 (REUSE)	8.90	-	8.70	1.07	8.71	

1.2 PROGRAM DEFINITION AND OBJECTIVES

The Space Tug is a reusable vehicle designed to operate in conjunction with the NASA Space Shuttle. The Tug is transported by the Space Shuttle to low Earth orbit, where it then performs as a propulsive stage for placement and retrieval of payloads in higher-energy orbits including synchronous altitudes. When transporting the Tug and payload, the Space Shuttle Orbiter is capable of deploying 65,000 lb to a 160-nmi circular orbit. The Orbiter also retrieves the Tug after it performs its mission from a similar orbit for return to Earth. For the purpose of this system study, the Tug is to be a cryogenic propulsive stage that uses liquid hydrogen and liquid oxygen as propellants.

Cryogenic Tug Option 2 is a direct development program that is to provide an initial operating capability (IOC) on December 31, 1983. In developing the complete description of this program option, the following were to be given principal emphasis:

- Minimum performance, retrieve $\geq$3,500 lb from geosynchronous orbit
- Tug designed to rendezvous and dock
- Meet minimum payload requirements, provide 300 watts
- Low-cost design, development, test, and evaluation (DDT&E) with total program cost effectiveness
- Six-day mission ability.

Additional ground rules assumed for this option are as follows:

- Multimission capability with three payloads
- Payload spin-up capability
- Telemetry relay for payload checkout
- Manual adjusted payload interface diameter.

Within the Option 2 capability, three specific sensitivities were to be investigated:

A. Programmatic sensitivity for a two-year-earlier IOC (December 31, 1981).

B. Programmatic and configuration requirements to provide 13-day servicing mission ability for the option available at December 31, 1981. This is for the Tug only; there are no other special requirements for payloads. For this case, the Tug was to be optimized for a 13-day mission, with ability to meet the minimum performance.

C. Sensitivity impacts of using Aerospace Support Equipment (ASE), aerospike and RL-10 Category IV engines.

The physical and performance characteristics of Option 2 are shown in Table 1-

Table [illegible]-1

VEHICLE CHARACTERISTICS

PROGRAM OPTION 2

CAPABILITY OPTION DIRECT DEVELOPED-DEPLOY AND RETRIEVE IOC DATE DECEMBER 31, 1983

PROGRAM OBJECTIVE LOW OVERALL PROGRAM COST - RETRIEVE 3,500 LB FROM GEOSYNCHRONOUS ORBIT

PHYSICAL CHARACTERISTICS

Main Engine Type	CAT IIA RL10
Mixture Ratio	6:1
Thrust	15,000 LB
ISP	459.2 SEC
APS Type	STORE BIPROP
I_{SP}	264 SEC
Weight Summary	
Burnout Weight	6,430 LB
Gross Weight (Less Payload)	63,120 LB
Usable Propellant	55,932 LB
*Stage Mass Fraction (λ')	0.886
Performance Summary	
Payload Deployed (Geosync)	7,640 LB
Payload Retrieved (Geosync)	4,810 LB
Payload Round Trip (Geosync)	2,950 LB
Structural Configuration	LCS
Stage Length	34.2 FT

PROGRAM CHARACTERISTICS

Autonomy Level	III
Development Time (To IOC)	55 MO
Mission Completion Probability**	0.932/0.971
Fleet Size	12
Number of Flights (ETR/WTR)	177/45
Reusable (ETR/WTR)	171/45
Expendable (ETR/WTR	6/0
Ground Turnaround Time ***	20.5/21.3
Cost Summary ($ 1973 Millions)	
Program Cost	682.50
DDT&E Cost	298.77
Peak Year Funding	124/FY'82
Operations Cost/Flight (Avg.)	0.76
First Unit Cost	18.08
SR&T Cost	15.44

**6 Day Mission/with Kick Stage

***Working Days (ETR/WTR)

* λ' = Total Usable Capacity/Gross Weight (Less Payload)

Section 2
CONFIGURATION DEFINITION

2.1 SPACE TUG VEHICLE MAIN STAGE (WBS 320-03)

Option 2 for the Cryogenic Tug will contain 55,932 lb of usable LH_2 and LO_2 propellants for operation of its Category II RL-10 main engine. The configuration (Figure 2-1) consists of primary structure, thermal control provisions, avionics and propulsion subsystems, and Shuttle and payload interface accommodations. The vehicle has an overall diameter of 176 in. (14.7 ft) and a total length without payload of 411.8 in. (34.3 ft). The stage dry weight and launch weight less payload are 5,620 lb and 63,120 lb, respectively.

2.2 STRUCTURES SUBSYSTEM SUMMARY (WBS 320-03-01)

The structural concept is designed to meet the program requirements establishe for Option 2, as described in Section 1.

The structural arrangement of this configuration is shown in Figure 2-2. Table 2-1 provides the structural materials used.

Table 2-1.
STRUCTURAL/MATERIALS

Configuration: Load-carrying shell

Tankage: 2219 Al, tapered 1-pc cassinian domes

LH_2 sidewall 2219 Al monocoque

Tank Supports: Laced, tubular fiber glass/epoxy trusses

Body Structure: Graphite/epoxy faced, Al core honeycomb shell forward

honeycomb shear panels/graphite epoxy longerons aft

Thrust Structure: Fiber glass/epoxy open isogrid flat panels

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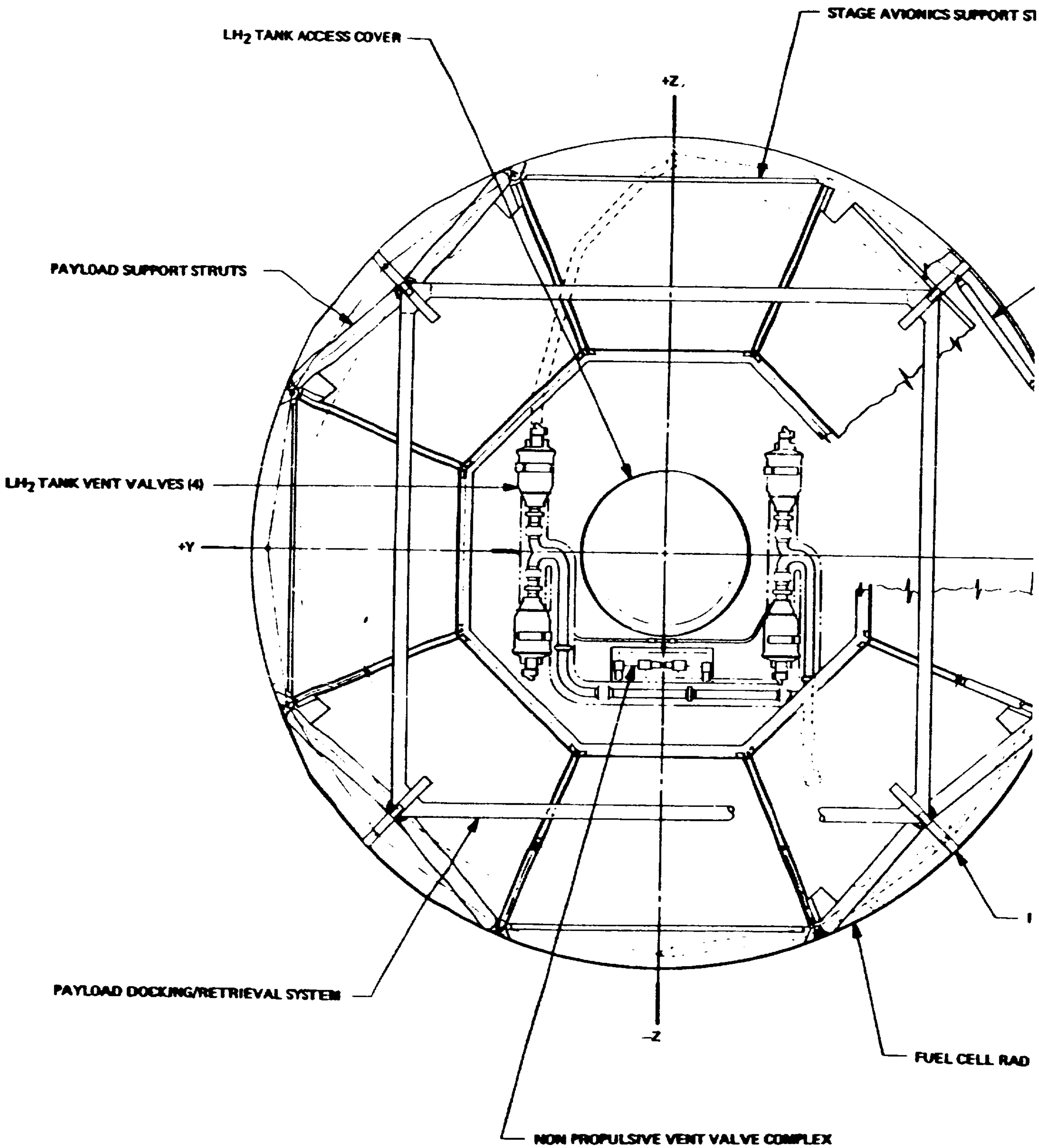
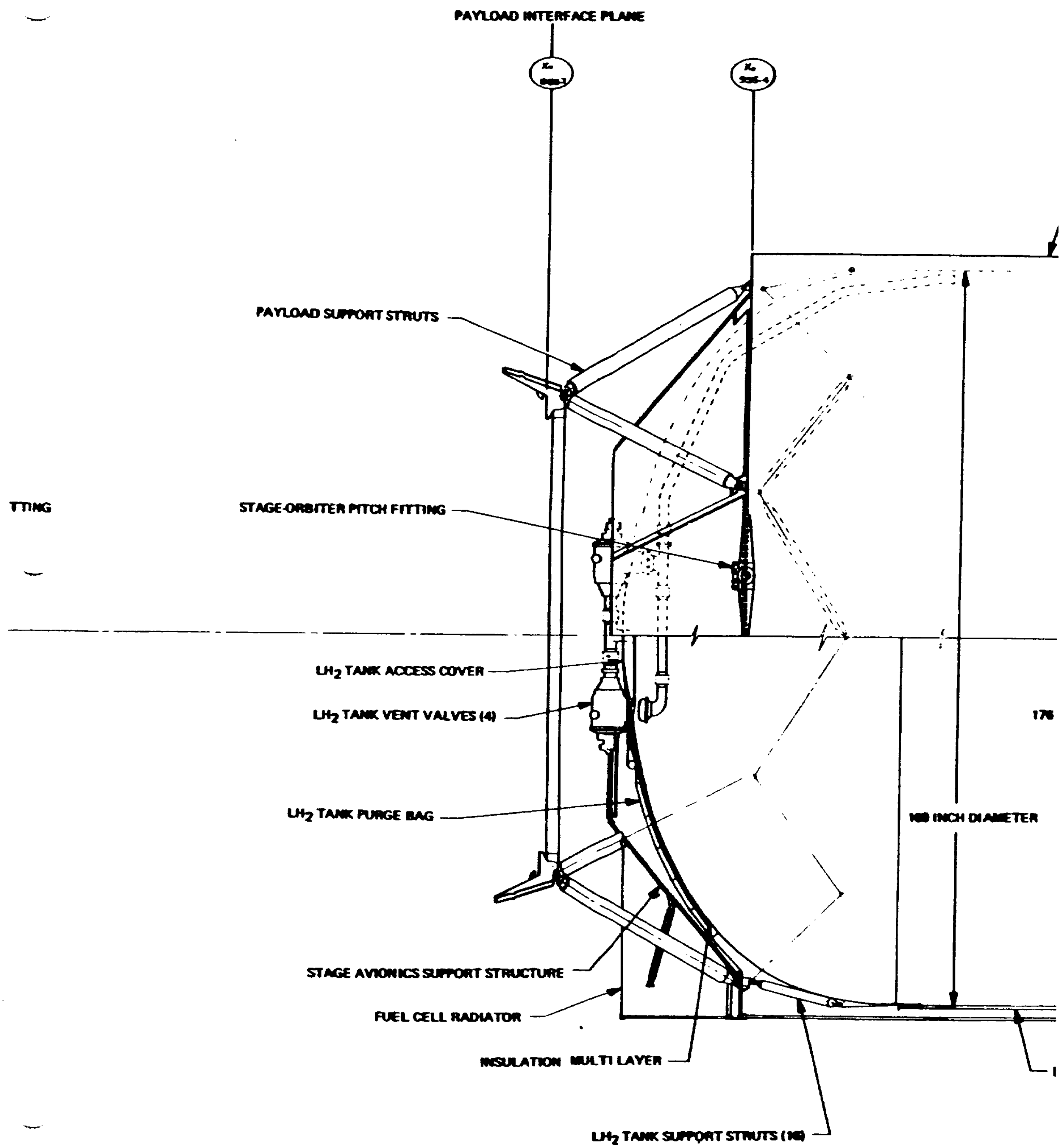
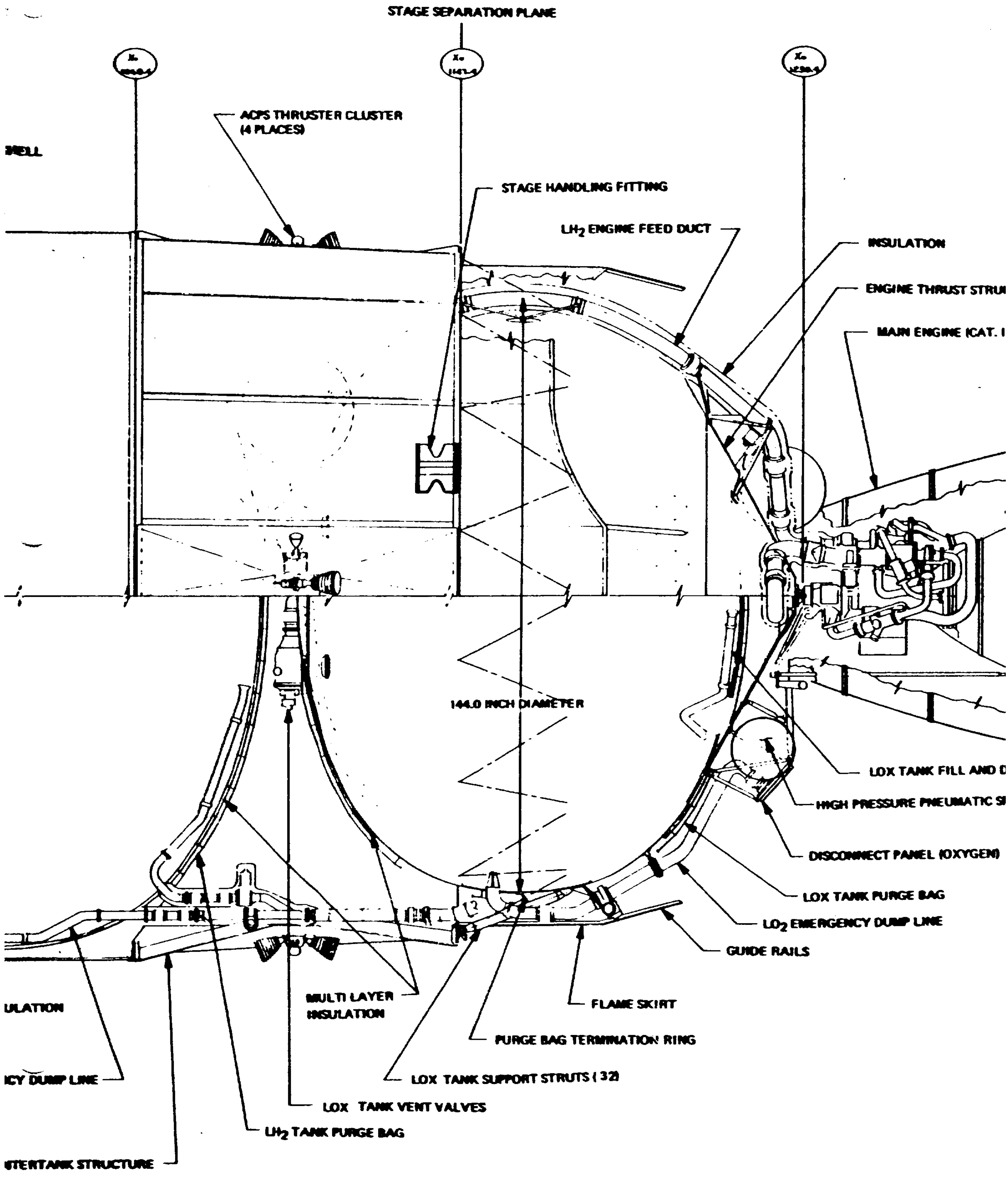
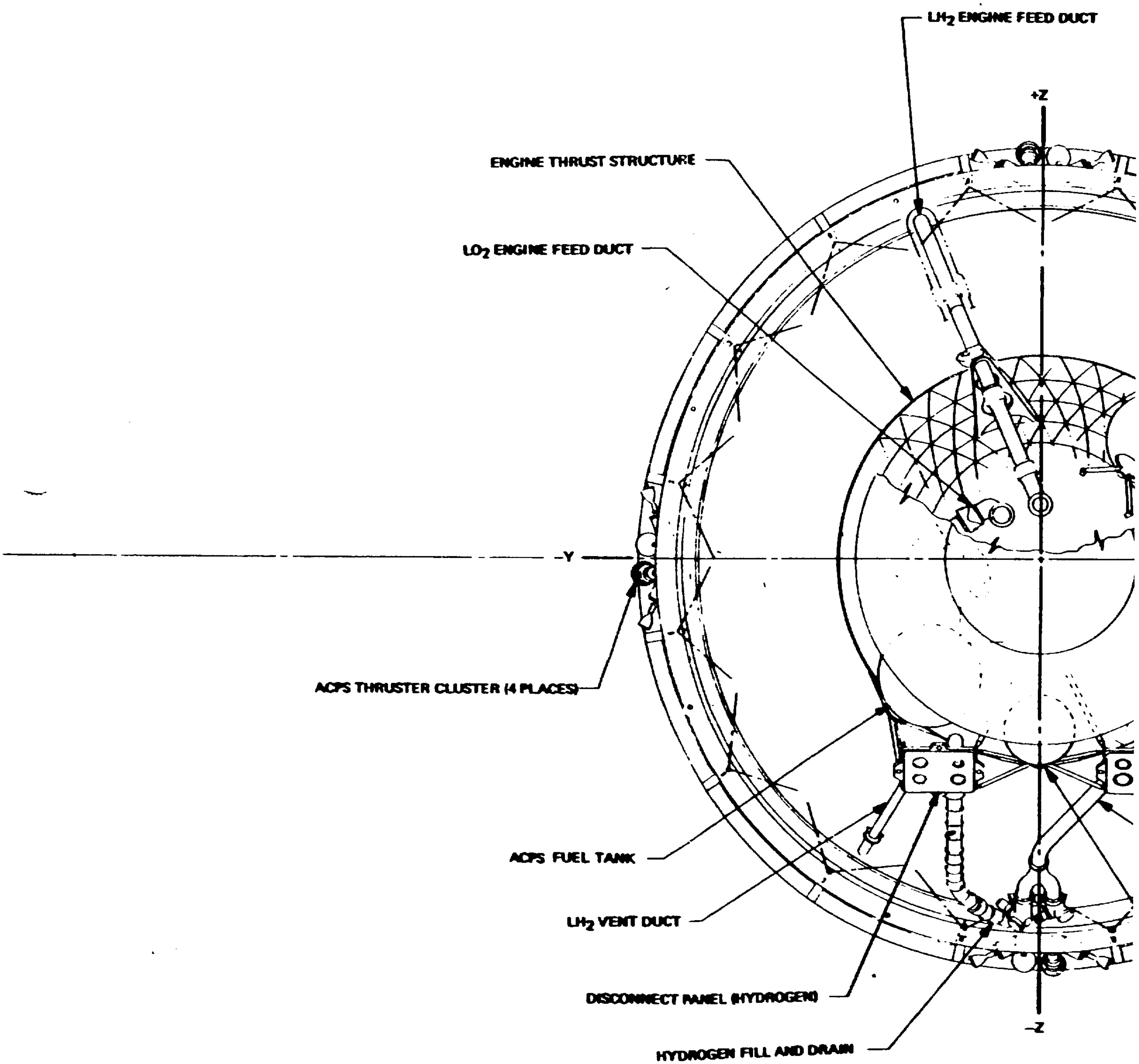


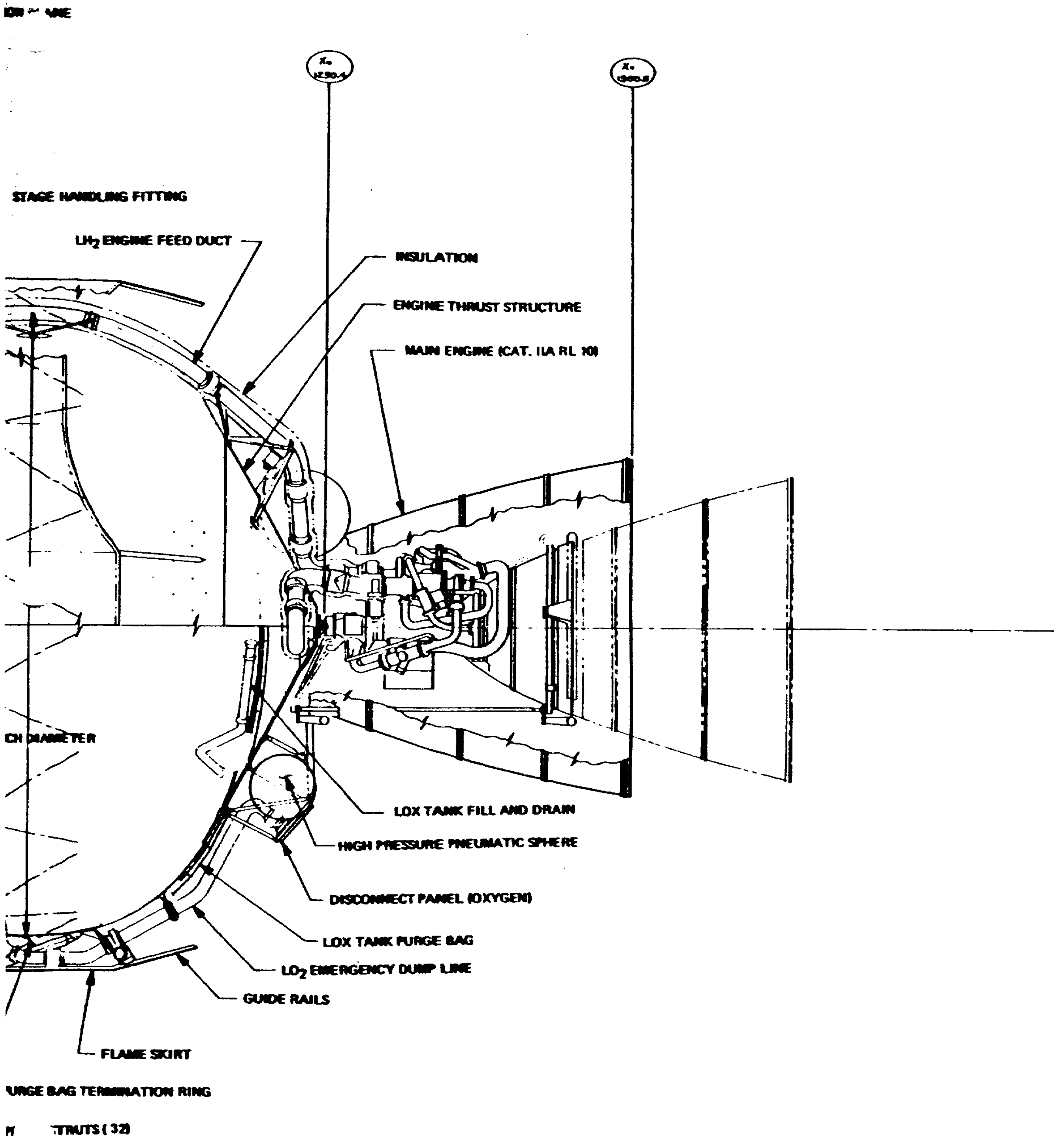
LH2 TANK ACCESS COVER
STAGE AVIONICS SUPPORT ST
+Z
PAYLOAD SUPPORT STRUTS
LH2 TANK VENT VALVES (4)
+Y
PAYLOAD DOCKING/RETRIEVAL SYSTEM
–Z
FUEL CELL RAD
NON PROPULSIVE VENT VALVE COMPLEX


PAYLOAD INTERFACE PLANE
PAYLOAD SUPPORT STRUTS
TTING
STAGE-ORBITER PITCH FITTING
LH2 TANK ACCESS COVER
LH2 TANK VENT VALVES (4)
176
LH2 TANK PURGE BAG
INCH DIAMETER
STAGE AVIONICS SUPPORT STRUCTURE
FUEL CELL RADIATOR
INSULATION MULTI LAYER
LH2 TANK SUPPORT STRUTS



STAGE SEPARATION PLANE
ACPS THRUSTER CLUSTER (4 PLACES)
STAGE HANDLING FITTING
LH_2 ENGINE FEED DUCT
INSULATION
ENGINE THRUST STRU
MAIN ENGINE (CAT. I
144.0 INCH DIAMETER
LOX TANK FILL AND D
HIGH PRESSURE PNEUMATIC S
DISCONNECT PANEL (OXYGEN)
LOX TANK PURGE BAG
LO_2 EMERGENCY DUMP LINE
GUIDE RAILS
FLAME SKIRT
PURGE BAG TERMINATION RING
LOX TANK SUPPORT STRUTS (32)
LOX TANK VENT VALVES
LH_2 TANK PURGE BAG
MULTI LAYER INSULATION
ULATION
ICY DUMP LINE
NTERTANK STRUCTURE


LH2 ENGINE FEED DUCT
+Z
ENGINE THRUST STRUCTURE
LO2 ENGINE FEED DUCT
-Y
ACPS THRUSTER CLUSTER (4 PLACES)
ACPS FUEL TANK
LH2 VENT DUCT
DISCONNECT PANEL (HYDROGEN)
HYDROGEN FILL AND DRAIN
-Z



STAGE HANDLING FITTING
LH_2 ENGINE FEED DUCT
INSULATION
ENGINE THRUST STRUCTURE
MAIN ENGINE (CAT. IIA RL 10)
CH DIAMETER
LOX TANK FILL AND DRAIN
HIGH PRESSURE PNEUMATIC SPHERE
DISCONNECT PANEL (OXYGEN)
LOX TANK PURGE BAG
LO_2 EMERGENCY DUMP LINE
GUIDE RAILS
FLAME SKIRT
URGE BAG TERMINATION RING
TRUTS (32)

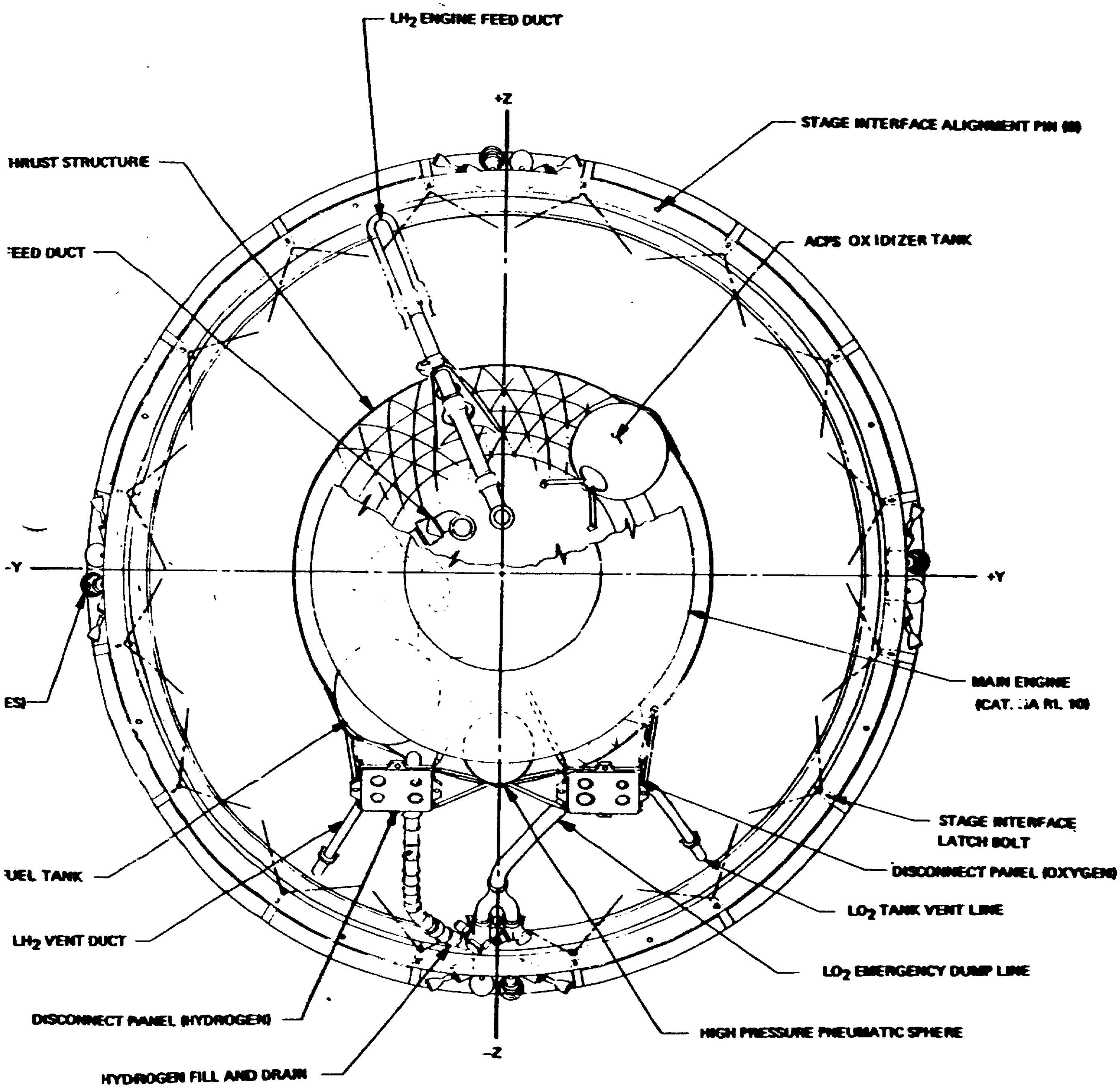
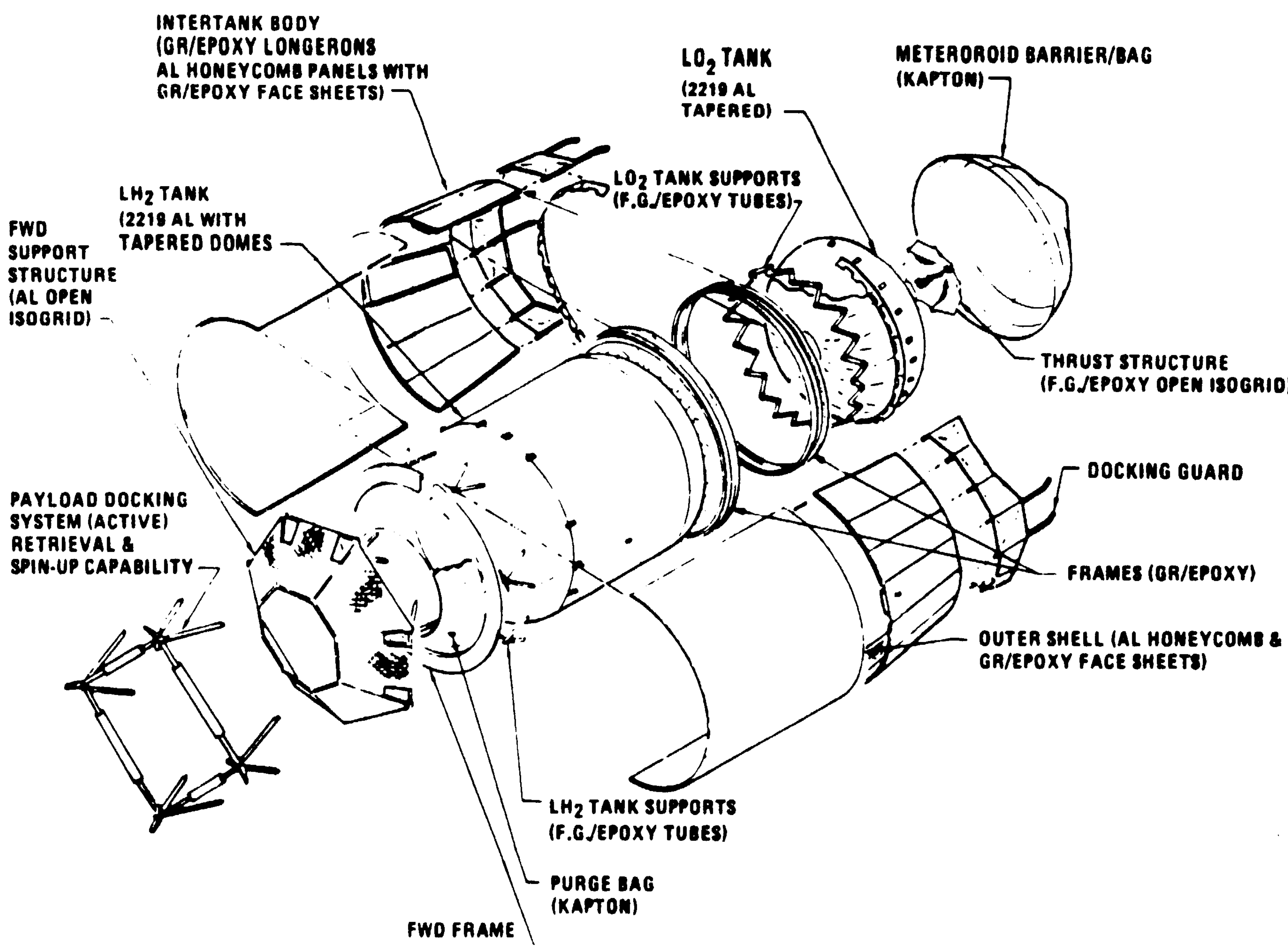

LH2 ENGINE FEED DUCT
+Z
STAGE INTERFACE ALIGNMENT PIN (8)
HRUST STRUCTURE
ACPS OXIDIZER TANK
FEED DUCT
-Y
+Y
MAIN ENGINE
ES)
STAGE INTERFACE
LATCH BOLT
UEL TANK
DISCONNECT PANEL (OXYGEN)
LO2 TANK VENT LINE
LH2 VENT DUCT
LO2 EMERGENCY DUMP LINE
DISCONNECT PANEL (HYDROGEN)
HIGH PRESSURE PNEUMATIC SPHERE
-Z
HYDROGEN FILL AND DRAIN

Figure 2-1.



INTERTANK BODY (GR/EPOXY LONGERONS AL HONEYCOMB PANELS WITH GR/EPOXY FACE SHEETS)
LO_2 TANK (2219 AL TAPERED)
METEROROID BARRIER/BAG (KAPTON)
LH_2 TANK (2219 AL WITH TAPERED DOMES
FWD SUPPORT STRUCTURE (AL OPEN ISOGRID)
LO_2 TANK SUPPORTS (F.G./EPOXY TUBES)
THRUST STRUCTURE (F.G./EPOXY OPEN ISOGRID)
DOCKING GUARD
PAYLOAD DOCKING SYSTEM (ACTIVE) RETRIEVAL & SPIN-UP CAPABILITY
FRAMES (GR/EPOXY)
OUTER SHELL (AL HONEYCOMB & GR/EPOXY FACE SHEETS)
LH_2 TANK SUPPORTS (F.G./EPOXY TUBES)
PURGE BAG (KAPTON)
FWD FRAME

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A honeycomb cylindrical shell of graphite/epoxy face sheets over an aluminum core is employed from the forward support frame to aft of the fuel tank cylinder. Concentrated loads from the payload support trusses and from the fuel tank support trusses and uniform loads from the avionics mounting panels are introduced into the forward end of the shell. A composite forward frame distributes these loads and the pitch-fitting forward reaction loads into the shell. At the aft end, longerons in the conic intertank shell carry the ben and axial loads to hard points on the stage support. Composite honeycomb panels, alternately fixed and hinged, provide shear surfaces for bending and torsional shear loading, and also stabilize the longerons.

Both fuel and oxidizer tanks are made of 2219 aluminum with tapered, one-pie cassinian domes. The fuel tank cylinder is a 2219 aluminum monocoque. Supp for both tanks is provided by laced tubular trusses of fiber glass/epoxy wit attachment to the LH_2 tank at the forward dome-cylinder joint and to the LO_2 tank tangentially on the aft dome. Fuel tank loads are transmitted into the shell forward frame while the LO_2 tank support reactions are carried directl into the stage support structure at the separation plane on the aft end of t Tug.

An open isogrid conic thrust structure carries engine thrust into the tank a 12 hard-point pads. The 12 flat fiber glass/epoxy panels are joined at thei edges and tangentially attached to the aft dome of the LO_2 tank.

At the forward end of the stage, avionics support is provided by eight flat aluminum isogrid panels nested in a flat cone over the tank dome and attache as indicated to the forward frame. Integral heat sink pads are included for heat conduction from the thermal control heat pipes to the components.

Meteoroid protection is provided by the shell and the insulation. No furthe protection is required to prevent tank damage. At the forward and aft ends of the stage, the purge bag/insulation provides the required barrier.

Structural analysis and trade studies are discussed in detail in Volume 5.

2.3 THERMAL CONTROL SUBSYSTEM SUMMARY (WBS 320-03-02)

The thermal control system is designed to meet the program requirements established for Option 2.

Thermal control of the fuel and oxidizer tanks is accomplished with a multilayer insulation (MLI) system. Alternate layers of double aluminized Mylar (DAM) and a Dacron net were selected for the MLI. The layers are held together in an integral panel with fasteners which have a small-diameter shank. The outer layers of the MLI panels are face sheets which protect the panel and which carry the structural loads. The panels are joined at their edges by lacing and Velcro. This insulation concept is shown in Figure 2-3.

Separate bags envelop each of the tanks. These bags ensure the presence of gases which will not liquefy or freeze on the tank exterior and the insulation system during ground hold, ascent, and reentry. Helium is used for both preflight purging and reentry repressurization of the bag. Large valves in the bags and standoffs, which maintain a gap between the MLI and the bag, are used to allow a rapid evacuation of the purge gas during ascent. Pressure controllers are used to control the repressurization of the bags during reentry. Standoffs between the tank and MLI as well as the standoffs between the MLI and the bag facilitate purging the system. A schematic of the purge system is shown in Figure 2-4.

Thermal analyses and studies are discussed in detail in Volume 5.

2.4 AVIONICS SUBSYSTEM SUMMARY (WBS 320-03-03)

Program Option 2 is designed to minimize total program cost. In addition, the mission duration is 144 hours, and payload retrieval capability is required. Autonomy Level III is used since studies have shown that Level III results in the lowest total program costs. The 144-hour mission duration requires all subsystems to contain at least one level of redundancy and use fuel cells instead of batteries.

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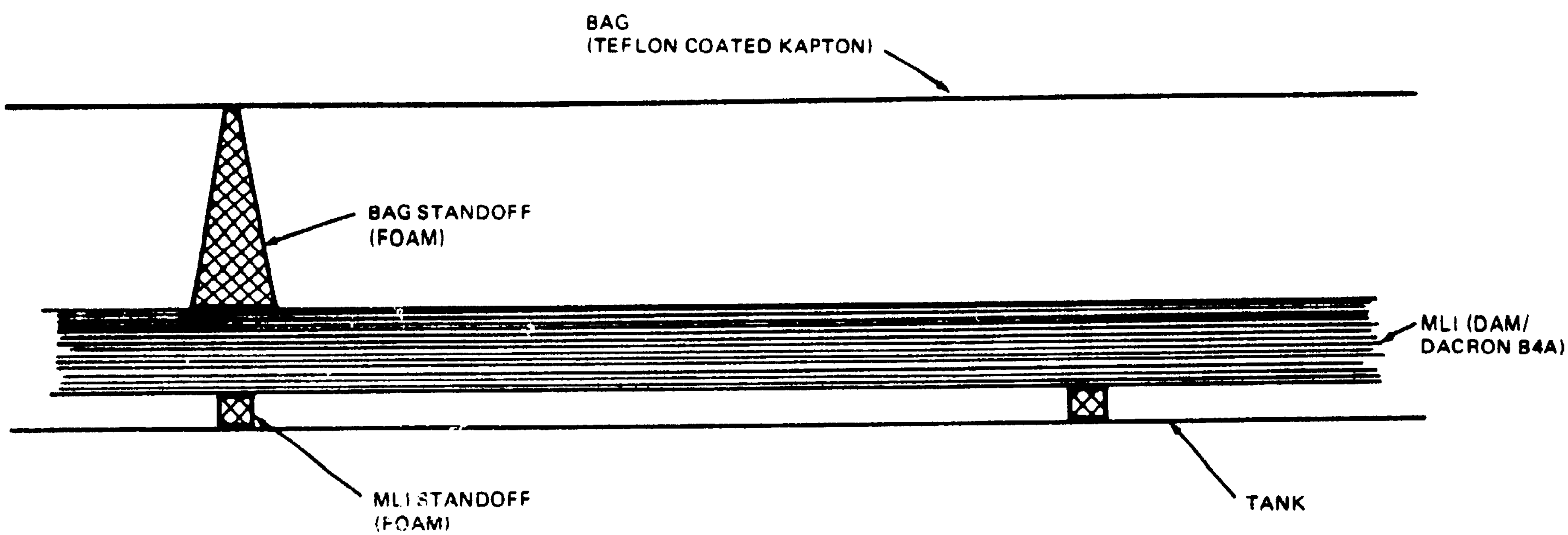

Figure 2-3. LH_2 and LO_2 Tank Insulation System

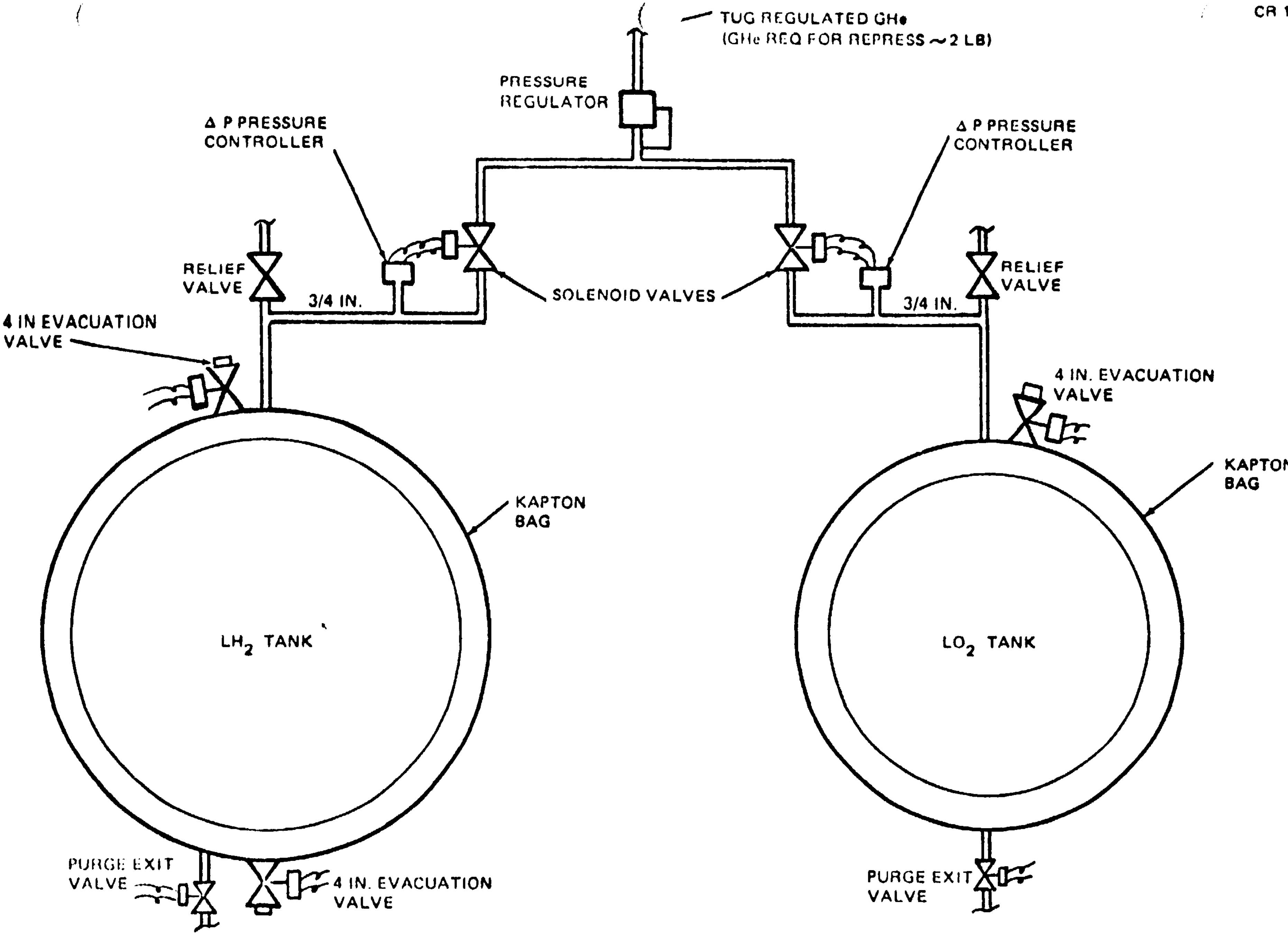

Figure 2-4. Purge, Evacuation, and Repressurization System Schematic

The data management system utilizes redundant 16-bit central computers. A 16-bit computer was selected due to its lower cost and higher reliability and because autonomy Level III allows a portion of the calculation requiring 24 to 32 bit accuracy to be performed on the ground. Remote data processors are not required in this option since the Micron inertial measurement unit (IMU) selected utilizes electrostatic gyros that read out attitude directly and therefore do not require direction cosine update calculations. The IMU calculations have been incorporated in the central computer.

The onboard software will perform all calculations required for flight control guidance, attitude update, and subsystem control and redundancy management. Those calculations required to update vehicle position and velocity and augment onboard subsystem control will be performed on the ground. The result of the ground calculations will be uplinked to the vehicle.

The Micron IMU was selected because of its relative lower recurring cost. The Orbiting Astronomical Observatory (OAO) strapdown star tracker was selected since it minimizes cost. A strapdown star tracker constrains vehicle attitude but since the vehicle position/velocity are updated from the ground in autonomy Level III, relatively few attitude updates will be required - they are only required prior to main engine burns - and therefore the attitude will be constrained only for short periods of time.

A laser radar was selected for the rendezvous/docking sensor in lieu of a radar-TV combination. The laser radar-only option was selected to minimize the vehicle weight and because of the inability of the TV to control low-Earth orbit docking operation. (This is still pending further definition of the tracking and data relay satellite capability).

The communications subsystem design is based primarily on the use of existing components. Only the minimum uplink and downlink services have been provided. A TM-uplink interface is provided to the Shuttle. The interface with the payload allows interleaving of the payload-Tug TM data and routing of payload uplink commands from the Tug to the payload. No payload checkout capability has been provided. NASA and DOD compatibility is achieved by component switching. The subsystem is redundant so that no single-point failure will result in loss of communication. This redundancy is achieved by parts internal to the units in most cases.

Fuel cells were selected as the power source to minimize the weight penalty for the longer-duration missions. Two fuel cells are provided, and since either is capable of handling the total vehicle load, a backup power source is not required. A separate AgZn battery has been provided for the thrust vector control (TVC) system to eliminate large peak power demands on the fuel cells and to keep these power transients off the main power busses.

The avionics subsystem characteristics are given in Table 2-2. A block diagram of the system is given in Figure 2-5.

Avionics analyses and trade studies are discussed in detail in Volume 5.

Thermal control for the avionics modules in the front of the vehicle is provided by lightweight radiation shields. Shields are installed over the panels in the forward skirt to provide radiation protection when the vehicle orientation is toward the sun. Heaters are provided for an orientation away from the sun. Heat pipes are used to pump heat from the hot side to the cold side when the vehicle is oriented at right angles to the sun. Heat pipes are also used to control the temperature of the midskirt electronics to stabilize the temperature of the electronic modules. The final design goal is to avoid operational constraints on vehicle orientation imposed by the onboard electronics thermal control requirements.

2.5 PROPULSION SUBSYSTEM SUMMARY (WBS 320-03-04)

The propulsion system is designed to the program requirements established for Option 2.

The selected subassemblies for the propulsion subsystem are defined to emphasize these requirements and are summarized in this section. The assemblies discussed are the main engine, main engine support, attitude control propulsion system (ACPS) engine, and ACPS engine support.

AVIONICS SUBSYSTEM CHARACTERISTICS

Subsystem	QTY	Weight (lb)	Power (W)
Data Management Subsystem (DMS)			
Central Computer	2	32	82
System Control Unit	1	8	12
Data Control Unit	2	16	24
Computer Interface Unit	1	2.6	2
Modular Interface Unit			
BIU	12	33.6	115.9
PCU	22	59	66
DCU	20	49	32
RMU	20	53	66
DIU	2	5	3
SCU	6	16	6
Wire Harnesses (All except power)	50	144	--
Connectors	700	87.5	--
Total (DMS)		475.7	408.9

Major Subsystem Characteristics/Description:

- Control Computer – 16-bit word length; 32,000 word memory; 2.6 μsec add time
- 1-mbit data bus
- SCU manages the redundant central computers
- Computers are MOS-LSI with plated wire memory
- PCU – Electronic circuit breaker controls 16 power channels
- DIU – Serial digital interface between CMD/TLM bus and LRU's
- RMU – Remote multiplexer accepts any combination of bilevel or analog input signals for 64 channels
- DCU – Low power switch controls up to 32 logic channels
- SCU – Provides amplification from 20 mvdc to 5 vdc for 32 low-level analog channels
- MIU – Submodules are fabricated with beam lead devices mounted on ceramic substrates for maximum reliability

Subsystem	QTY	Weight (lb)	Power (W)	Description
Guidance and Navigation Subsystem (G&N)				
Micron IMU	2	20	60	Miniature ESG IMU – Lightweight low-power – 2 skewed IMU's
Strapdown Startracker	2	20	20	Strapdown startracker $8^{\circ} \times 8^{\circ}$ FOV (space qualified - OAO)
Laser Radar	1	40	35	Automatic docking
Total (G&N)		80	115	All-altitude capability – 10.0 nmi placement Accuracy

Subsystem	QTY	Weight (lb)	Power (W)
Communication Subsystem (Comm)			
Omni Antenna	4	10	--
RF Multiplexer	1	4	--
Power Amplifier	2	16	74/144
STDN Transponder	1	26	32
SGLS Transponder	1	12	36
Command Decoder	1	5	5
PCM Encoder	1	3	4
Tape Recorder	2	40	25
Comsec Equipment	2	12	14
Mod/Demod Processor	1	14	13
Microwave Circuitry	1	24	20
Total (Comm)		166	293

- Dual multiservice S-band system
- Compatible with STDN and AFSCS
- Redundant uplink and downlink
- Omni-antennas for all-attitude RF coverage
- Microwave circuitry selects antennas singly or in pairs
- RF channel multiplexer acts as channel separator for USB and SGLS transmit/receive signals
- Transponders provide tracking, ranging, transmission of PCM telemetry and reception of uplink data
- Power amplifiers provide the necessary effective radiated power from tug to supply a margin above minimum required performance at the receiver
- Modulator/demodulator processor is used for signal-switching phase modulation (subcarriers) and demodulation of command subcarrier
- The command decoder detects, decodes, verifies, and distributes commands
- The PCM encoder combines the telemetry data into formats and clocks out the PCM data to be modulated on a subcarrier

Subsystem	QTY	Weight (lb)	Power (W)
Instrumentation Subsystem			
Transducers and Sensors		25	107
Instrumentation Power Supplies	6	36	54
Total (Instr)		61	161

Subsystem	QTY	Weight (lb)	Power (W)
Electrical Power Subsystem			
H_2-O_2 Fuel Cell Battery-Advance Technology, KOH Electrolyte	2	66	--
Silver-Zinc Primary Battery – 20 amp/hr	1	20	--
Oxygen Tank – 203-lb Capacity at 900 psi	1	64	--
Hydrogen Tank – 25-lb Capacity at 250 psi	1	69	--
Oxygen Reactant	—	218	
Hydrogen Reactant	--	27	--
Total (EPS)		484	

- O_2:H_2 weight = 8:1
- 0.92 lb combined per kilowatt-hour
- AgZn primary battery for TVC power
- Either fuel cell can supply total power
- Supercritical reactant storage
- Reactant tanks based on Gemini reactant supply tanks

Subsystem	QTY	Weight (lb)	Power (W)
Electrical Power Distribution Subsystem			
Power Distribution Unit	1	21	50
Wire Harnesses	10	30	36
Total (EPDS)		51	86

- Electromechanical contactors driven by solid-state logic and drivers for bus control and protection
- Solid-state remote power controllers used for switching of MIU feeders and for main bus

Subsystem	QTY	Weight (lb)	Power (W)
Equipment Thermal Control			
Thermal Panels	--	89	--
Heat Pipes	--	26	--
Splice Mechanisms	--	30	--
Radiation Shroud	--	15	--
Miscellaneous	--	2	--

- Heat pipes have 1/2-in. square cross-section with stainless steel wick and ammonia working fluid: 10 ft long sealed sections curved to fit vehicles
- Splice mechanism provides thermal conductivity between 10 ft sealed heat pipe sections to form circumferential hoop beneath panels
- Eight mounting panels 7 to 19 ft^2 with heat pipes thermally attached to rear surface. Low

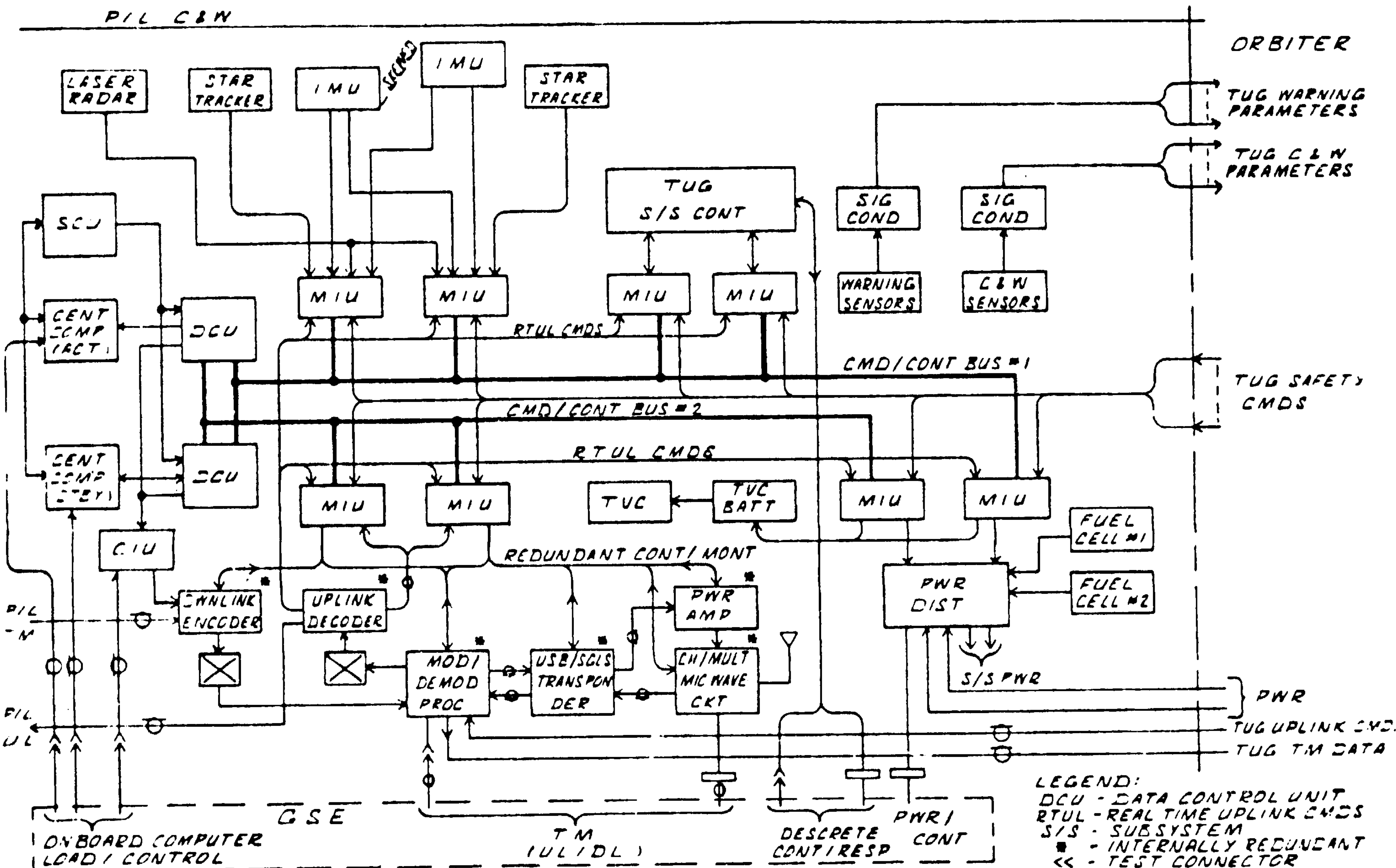

Figure 2-5. Avionics Block Diagram, Program Option 2

2.5.1 Main Engine

The Category IIA RL10 engine was selected for the Option 2 Tug, and the principal performance and geometric characteristics are:

Vacuum Thrust (lb)	15,000
Engine Mixture Ratio	6.0
Vacuum I_{sp} (sec)	459.2
Expansion Ratio	262:1
Dry Weight (lb)	476
Length (in.)	70 retracted; 127 deployed
Diameter (in.)	79.6
Additional Capability	Tank head idle; Retractable nozzle; Zero net positive suction head (NPS

*Without pumped idle mode

The main propulsion system schematic is shown in Figure 2-6. The figure show all of the Tug main propulsion subassemblies, plus the main propellant tank insulation vent and purge. In addition, it shows the fluid lines and hardwar in the Orbiter payload bay and Orbiter aft section which support the Tug.

The Option 2 Tug features a Category IIA RL10 main engine which has zero NPSH capability and does not require a pressurization system. However, an ambient helium assembly will be provided during flight test for repressurization back-up until low-chamber-pressure start capability is verified. Also shown are the vent, main engine feed, fill and drain, LO_2 suborbital dump, and LH_2 horizontal drain subassemblies.

The Orbiter side of the interface shows the LH_2 tank purge helium provisions and the ambient helium fill, fill and drain, main tank vent, orbital dump, an LO_2 suborbital abort dump line provisions. Fuel cell LH_2 and LO_2 reactant supply lines are also required for this option.

2.5.2 Main Engine Support

The Option 1 main engine support assembly is basically composed of hardware subassemblies (feed, fill and drain, etc.). However, nonhardware selections

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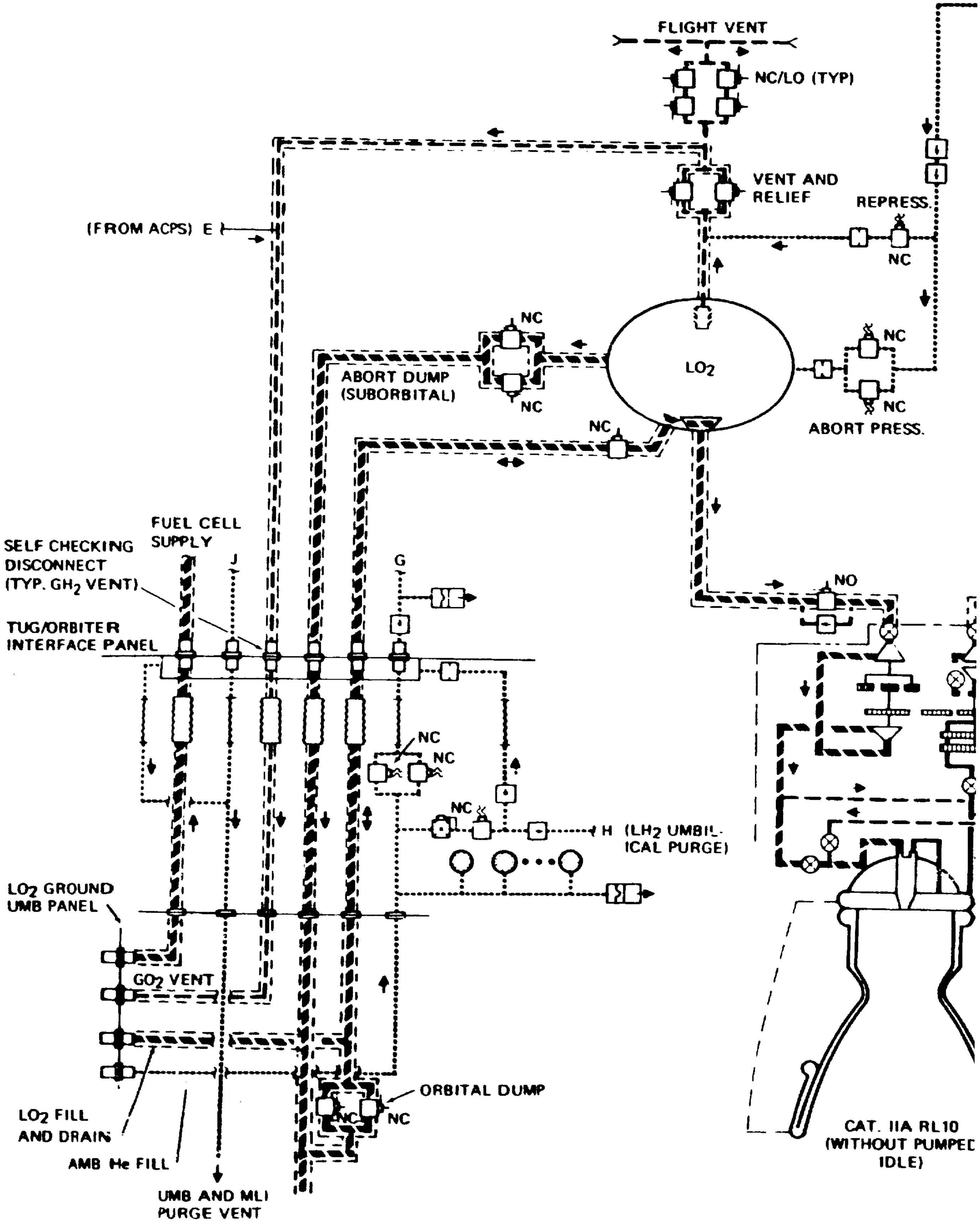
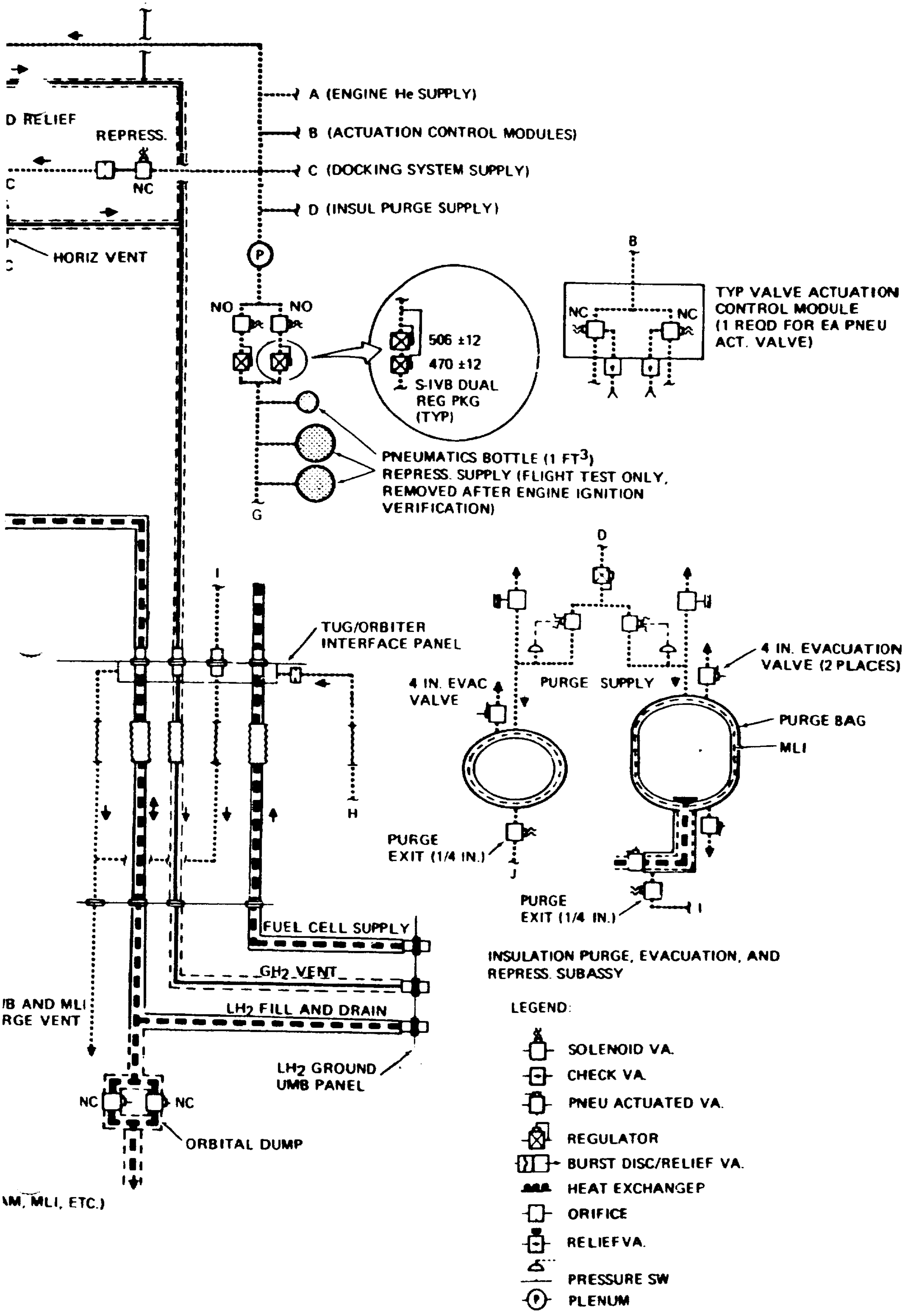


FLIGHT VENT
NC/LO (TYP)
VENT AND RELIEF
REPRESS.
NC
(FROM ACPS) E
NC
LO_2
ABORT DUMP (SUBORBITAL)
NC
NC
NC
NC
ABORT PRESS.
NO
FUEL CELL SUPPLY
SELF CHECKING DISCONNECT (TYP. GH_2 VENT)
J
G
TUG/ORBITER INTERFACE PANEL
NC
NC
NC
H (LH2 UMBILICAL PURGE)
LO_2 GROUND UMB PANEL
GO_2 VENT
ORBITAL DUMP
NC
NC
LO_2 FILL AND DRAIN
AMB He FILL
UMB AND MLI PURGE VENT
CAT. IIA RL10 (WITHOUT PUMPED IDLE)


A (ENGINE He SUPPLY)
B (ACTUATION CONTROL MODULES)
C (DOCKING SYSTEM SUPPLY)
D (INSUL PURGE SUPPLY)
D RELIEF
REPRESS.
NC
HORIZ VENT
NO
NO
506 ±12
470 ±12
S-IVB DUAL
REG PKG
(TYP)
PNEUMATICS BOTTLE (1 FT^3)
REPRESS. SUPPLY (FLIGHT TEST ONLY, REMOVED AFTER ENGINE IGNITION VERIFICATION)
G
B
NC
NC
TYP VALVE ACTUATION CONTROL MODULE (1 REQD FOR EA PNEU ACT. VALVE)
TUG/ORBITER INTERFACE PANEL
H
D
4 IN. EVACUATION VALVE (2 PLACES)
4 IN. EVAC VALVE
PURGE SUPPLY
PURGE BAG
MLI
PURGE EXIT (1/4 IN.)
J
PURGE EXIT (1/4 IN.)
I
FUEL CELL SUPPLY
GH_2 VENT
LH_2 FILL AND DRAIN
IB AND MLI
RGE VENT
LH_2 GROUND UMB PANEL
NC
NC
ORBITAL DUMP
AM, MLI, ETC.)
INSULATION PURGE, EVACUATION, AND REPRESS. SUBASSY
LEGEND:
SOLENOID VA.
CHECK VA.
PNEU ACTUATED VA.
REGULATOR
BURST DISC/RELIEF VA.
HEAT EXCHANGEP
ORIFICE
RELIEF VA.
PRESSURE SW
PLENUM

are also included in this category; i.e., main tank propellant orientation, and feedline and engine thermal conditioning. The main engine support selections are shown in Table 2-3.

2.5.3 Attitude Control Propulsion System

The ACPS system utilizes bipropellants (MMH/N_2O_4) pressurized by a regulated helium supply. The helium is stored in a 1-cu-ft high pressure sphere, and regulated to the propellant tanks by a network of redundant regulators.

The propellants are contained within Co-dispersion Teflon bladders inside spherical propellant tanks. The propellants are initially vacuum-loaded and then pressurized by the regulated helium. Propellant is directed to each of four thruster pods via a propellant feed system. A network of isolation valves in the propellant feed system provides fail-operational/fail-safe performance. Each thruster pod contains four thrusters, two 90 lbf axial thrusters and two 22 lbf tangential thrusters.

The major performance characteristics of the system are presented in Table 2-4, followed by a description and source identification of the major components in Table 2-5.

The schematic of the ACPS system with instrumentation is shown in Figure 2-7, which illustrates the fluid diagram as well as the electrical circuitry required for the regulated helium pressurization system. It shows the propellant tank manifolding, feed system to the thrusters, and the thruster and thruster module isolation valving required to achieve fail-operational/fail-safe reliability. The schematic also contains provisions for filling and draining propellants and for loading ambient helium.

2.6 SHUTTLE INTERFACE (WBS 320-03-05)

The Shuttle Orbiter-Tug interface subsystem is composed of the extensions of major Tug subsystems to the Orbiter which perform the major preflight, flight, and postflight operations. These operations are:

A. Preflight ground testing and checkout

B. Launch phase monitoring

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Table 2-3

MAIN ENGINE SUPPORT SUMMARY

OPTION 2

Main Engine TVC:	Apollo service propulsion system electromechanical actuators
Main Engine Feed:	LH_2 - 3.0-in. MLI wrapped ducting tank to new 3-in. prevalve Insulated 3-in. ducting with transition to 3.2 in. TBD in. prior to engine interface. LO_2 - 4.0-in. insulated ducting and Parker 4-in. prevalve. Ducting transition to 4.6 in. TBD in. prior to engine interface.
Vent (Typ for LH_2 and LO_2):	Six-valve configuration -- two Calmec vent and relief valves and four Calmec flight vent isolation valves. Vent ducting through Tug-Orbiter interface, 2.0 in. Flight vent, 1 in.
Fill and Drain:	LH_2 - 2.0-in. vacuum jacketed ducting and Parker 2-in. valve LO_2 - 2.0-in. insulated ducting and Parker 2-in. valve.
Pneumatics:	S-IVB derivative valves and controls, Pressure Systems, Inc. 1 sq ft^2 bottle.
Propellant Utilization:	Closed loop with capacitance probes.
Pressurization:	None on operational vehicles since zero NPSH engine. (Ambient He repressurization for flight test, however.)
Propellant Orientation:	Main engine tank head idle thrusting. Variable time depending on quantity of LH_2 in tank.
Engine and Feed-line Conditioning:	Condition feedline and engine while operating main engine in tank head idle mode.
LO_2 Abort Dump:	3.0-in. insulated ducting and parallel Fairchild butterfly valves.

Table 2-4

ACPS PERFORMANCE SUMMARY

Maximum Total Impulse Capacity	88,000 lbf sec
Maximum Total Impulse Required	73,000 lbf/sec
System Loaded Weight at Maximum Total Impulse Capacity	570 lbm
System Loaded Weight at Maximum Total Impulse Required	515 lbm
Thrust Level of Thrusters	90 lbf and 22 lbf
Degrees of Freedom of Attitude Control	6
Fail-Operational/Fail-Safe ACPS	Yes
Thruster Arrangement	4 pods of 4 each
Total Number of Thrusters	16
Number of Propellant Tanks	2

Table 2-5

ACPS MAJOR COMPONENT DESCRIPTION

Axial Thrusters	
Number Required	8
Model Number	R-4D
Manufacturer	Marquardt
Previous Program	Apollo SM
Tangential Thrusters	
Number Required	8
Model Number	R-1E
Manufacturer	Marquardt
Previous Program	MOL
Propellant Tanks	
umber Required	1 each, fuel and oxidizer
Previous Program	Gemini OAMS
Bladder Material	"CO-Dispersion" Teflon
Size	20-in.-dia Sphere

Table 2-5

ACPS MAJOR COMPONENT DESCRIPTION (Continued)

Volume (each)	4,130 cu. in.
Operating Pressure	224^{+7}_{-4} psia
Burst pressure	670 psia
Empty Weight	9.5 lbm
Helium Bottle	
Number Required	1
Previous Program	PT4
Size	15 in.-dia sphere
Volume	1,728 cu in.
Operating Pressure	3,600 psia
Burst Pressure	7,200 psig
Empty Weight	21.8 lbm
Helium Regulator	
Number Required	3
Model Number	6890
Manufacturer	Consolidated Controls
Previous Program	MM III PBPS
Regulator Outlet Pressure	224^{+7}_{-4} psia
Inlet Operating Pressure	3,640/450 psig
Inlet Burst Pressure	5,460 psig

D. Activation of subsystems

E. Deployment of the Tug-payload

F. Monitoring in Orbiter proximity

G. Monitoring during Tug mission operation

H. Command and control in Orbiter proximity

I. Subsystem deactivation

J. Retrieval of the Tug-payload

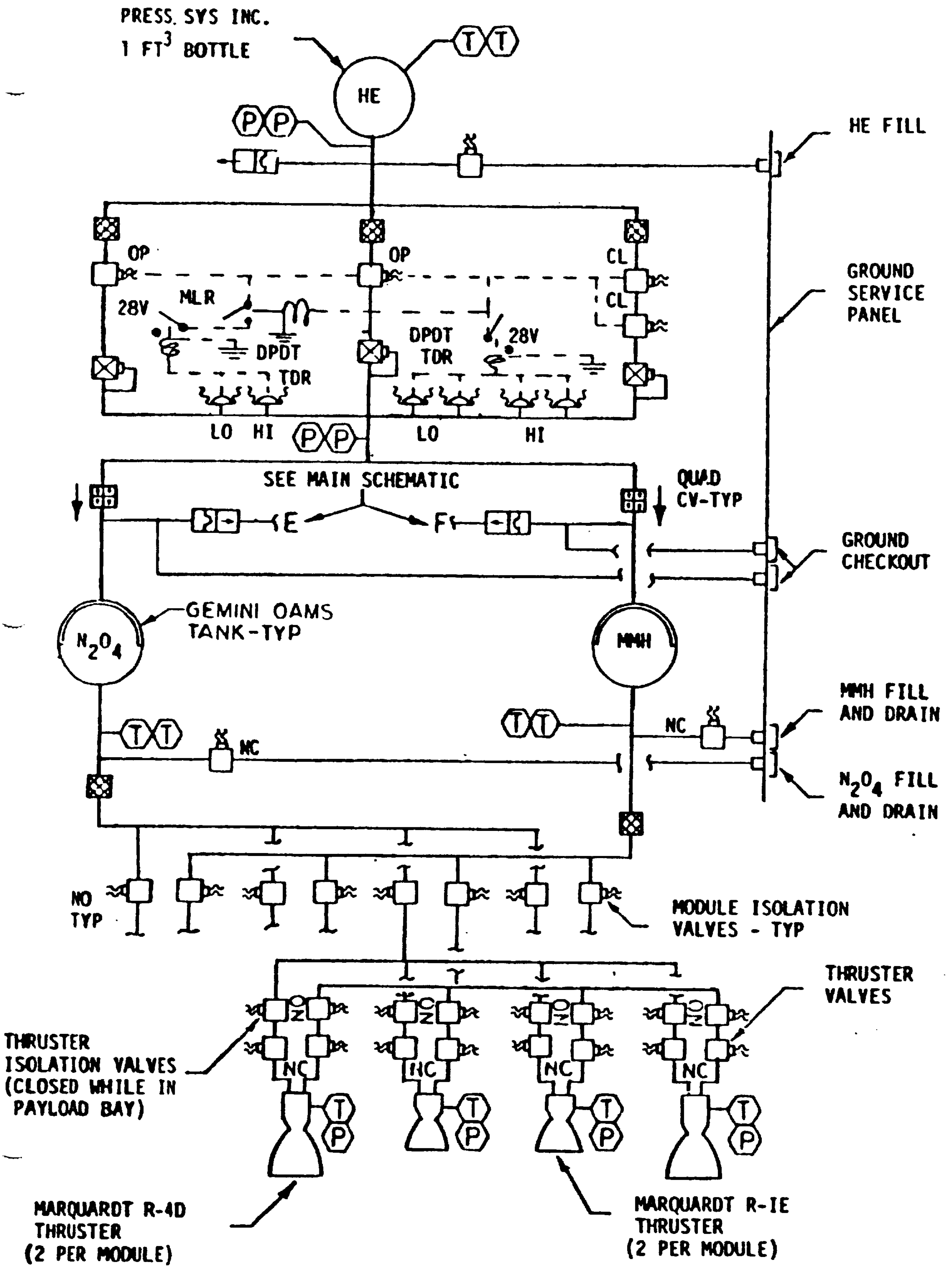
K. Stowage of the Tug-payload

L. Passivation and safing of Tug-payload

M. Return flight monitoring

N. Safety provisions

O. Ground support interfacing



PRESS. SYS INC.
1 FT3 BOTTLE
HE
T T
P P
HE FILL
OP
OP
CL
CL
MLR
28V
DPDT
TDR
DPDT
TDR
28V
LO
HI
LO
HI
GROUND
SERVICE
PANEL
SEE MAIN SCHEMATIC
E
F
QUAD
CV-TYP
GROUND
CHECKOUT
GEMINI OAMS
TANK-TYP
N2O4
MMH
NC
NC
MMH FILL
AND DRAIN
N2O4 FILL
AND DRAIN
NO
TYP
MODULE ISOLATION
VALVES - TYP
THRUSTER
VALVES
THRUSTER
ISOLATION VALVES
(CLOSED WHILE IN
PAYLOAD BAY)
NC
NC
NC
NC
MARQUARDT R-4D
THRUSTER
(2 PER MODULE)
MARQUARDT R-IE
THRUSTER
(2 PER MODULE)

The Shuttle Tug-Orbiter interface represents the provisions for mating two major systems, each of which is capable of independent operation when parted in space. While mated, the Tug depends to a degree on the support capability of the Orbiter and of the ground through the Orbiter. Although the vehicle is passive during most of the launch and landing periods, the Orbiter crew ensures continuous safety and monitors subsystem status.

The Shuttle Orbiter conducts many missions which do not include the Tug, however, and it is essential that the Tug interfaces produce minimum design and operational impacts upon the Orbiter. To minimize these impacts, the Tug ancillary hardware is designed for easy removal. The cabin provisions consist of a dedicated portion of the mission specialist station and multiplexed interfaces with the Shuttle Orbiter data management, computation, and display equipment. This allows accessing and display of Tug subsystem status for monitoring, diagnosis, and, through the Tug-unique dedicated panel sectio[n] sufficient control to take corrective action.

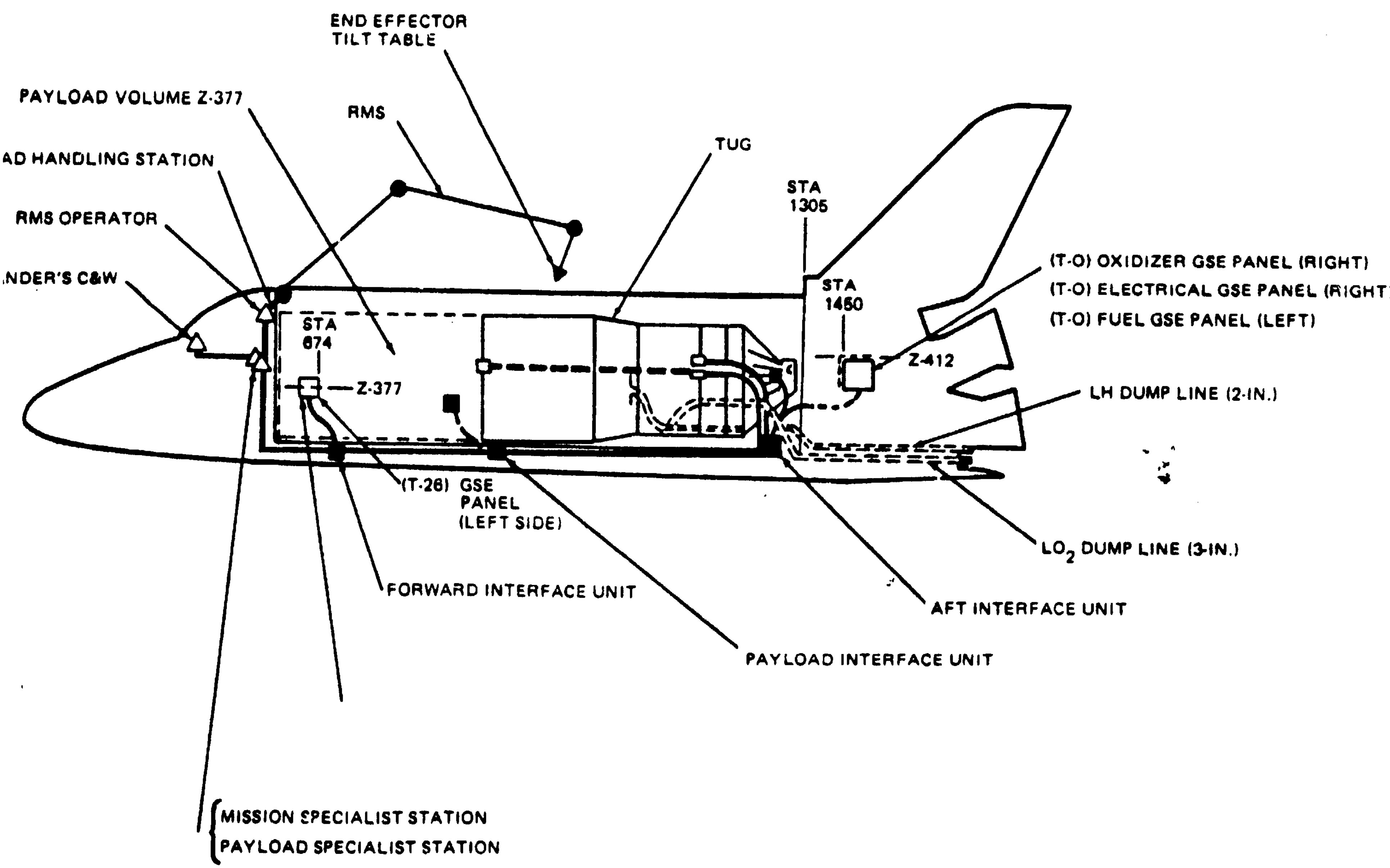
The principal functions and hardware groups are listed below and shown in Figure 2-8.

FUNCTIONS

Operations (listed above and discussed in Section 6).
Safety (discussed in Volume 7).
Structural/mechanical support (attachments, mountings, manipulation provision[s]
Fluid/propulsion support (fill/drain/vent/purge/abort provisions).
Thermal conditioning support (temperature control provisions).
Avionics support (electrical/electronics, checkout/monitor/control provisions, with data management, communications, electric power, guidance/navigation/control subsystems).
Payload support (checkout/monitoring, control, caution/warning, safing, electrical power circuits routed through the Tug).

HARDWARE GROUPS

Tug support structure (tilt table).
Tug support attachments (hard points, latches, locks, support frame adapters).
Remote manipulating system (RMS arm is part of Orbiter mechanisms. Tug-unique end effector with TV and lighting is charged to Tug support).
Fill/drain/vent/purge/abort line assemblies (includes vacuum-jacketed low



2-8. Shuttle-Tug Interfaces, Hardware Locations

Fluid panels and retraction mechanisms (purging provisions, locks, actuator drives, drive controls)

Electrical/electronics support (instrumentation, sensors, caution and warning circuits, electrical cables/connectors, interface units, junction boxes, test points. inhibit functions/circuits/buses, drive control electronics, TV/lighting)

The total weight of Shuttle interface hardware for Option 2 is 1,780 lb. The weight is detailed in the WBS weight statement in Volume 5. The hardware groups are described in Volume 5, Section 4.

2.7 PAYLOAD INTERFACE SUMMARY (WBS 320-03-01-06)

The payload interface structure is shown in Figure 2-1. It consists of four combination docking/structural latches. These latches are spring-loaded, pneumatically operated, and located at the corners of a shock strut mounted square frame. The eight struts are pneumatically deployed, hydraulically retracted gas shock absorbers. They are structurally locked in the retracted position by means of pneumatically operated spring-loaded internal ball latches. The interface structure was sized by a combination of maximum payload weight and Shuttle flight loads. The payload loads are carried through the shock struts into the Tug at the same forward frame hard point as the forward tank supports. The shock absorbing characteristics of the shock struts were determined from expected docking loads derived from established maximum docking parameters such as allowable closing velocities, misalignment, etc. The docking system is capable of retrieving spinning satellites and despinning them using the friction between the docking latches and the payload docking ring. Predeployment spin-up and post-retrieval indexing is provided by means of an electromechanical spin system. Details of this system are presented in Volume 5, Section 4.3. The interface diameter is variable from 8 to 13 ft by manually interchanging the square frame members.

The docking system is designed to meet or exceed the following contact condition requirements.

Radial Misalignment	± 6 in.
Longitudinal Velocity	0.1 to 1.0 fps
Lateral Velocity	0.3 fps

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Angular Misalignment	± 3 deg
Angular Rate	± 2.4 deg/sec
Spin Rate	up to 100 rpm

The electrical (avionics) interface consists of the necessary wires, connectors and fittings to provide relay of payload caution and warning parameters and normal payload telemetry data for Shuttle transmission while in the Orbiter bay. In addition, the payload may demand up to 300 watts of continuous power while attached to the Tug.

Operationally, payload deployment is achieved by first extending the docking frame. This motion assists in disconnecting the electrical interface as the frame moves away from the stage. Once extended, the corner latches are opened. The frame is then retracted and the Tug, which has been limit-cycling for fine hold, backs away from the payload.

When retrieving a payload, once proper Tug-payload orientation has been established with the laser radar guiding the APS, the docking frame is extended. The Tug then approaches the payload at the prescribed rate and one or more docking latches contact the payload's interface ring. The latches are individually triggered to the capture position as they make contact. The spin/indexing system is then moved into contact with the payload I/F ring, and the payload rotated to proper orientation for remake of the electrical interface. The indexing system is retracted and the latches moved to the structure locked position. The frame is then retracted and the ball latch latched.

2.8 AUXILIARY (KICK) STAGE SUMMARY (WBS 320-04-01)

The use of a kick stage on four of the NASA planetary missions (19, 20, 21, and 23) allows these missions to be flown in a reusable mode with the Tug. These were the only missions where the use of a kick stage was required.

A range of acceptable kick stage sizes was established parametrically. A survey of existing solid-rocket motors was made in an attempt to identify the existing stage which could be utilized for the Tug missions. Several constraints, such as stage length and thrust-to-weight, were used in making the final selection.

Design details of this stage are classified and may be found in the confid document Rocket Motors Manual (U) (Unit 411, Chemical Propulsion Informati Agency, John Hopkins University).

In an attempt to minimize changes to a standard Tug-payload interface, the payload-kick stage interface shown in Figure 2-9 was conceived. By replac standard Tug-payload interface truss with the one shown, the Tug-payload interface remains the same, with the exception that the interface plane mo forward. The longer struts allow the kick stage to interface directly wit the payload interface ring. There is no direct structual interface betwee the Tug and kick stage. The longer struts were designed by the combined pa load-kick stage loads. The electrical interface between the Tug and kick accommodated through the Tug-payload electrical interface panel. In essen the kick stage appears as part of the payload to the tug.

Operationally, the Tug separates from the payload-kick stage combination i same manner as separating from a payload. The Tug provides the proper fli path angle prior to separation. After an appropriate separation distance established, the kick stage is fired, completing the payload velocity requ ment. The kick stage must provide thrust vector control during its burn. Tug is then free to return to the Shuttle.

2.9 MASS PROPERTIES SUMMARY

2.9.1 Weight

The weights are summarized in Table 2-6. The weight breakdown is structure after the WBS breakdown and contains a 10 percent contingency on the total dry weight. A new element has been added called margin, which has permitte the weight analysis to continue to be refined up to the last moment and not force an iteration of the programmatics. This margin, although small (2.1 cent), gives increased confidence that the stage mass fraction can be achieved.

The weights presented herein are based upon the design defined in Volume 5, Book 2, Section 1. Additional weights and definition are included in the above volume, in Section 3, along with total vehicle mass properties.

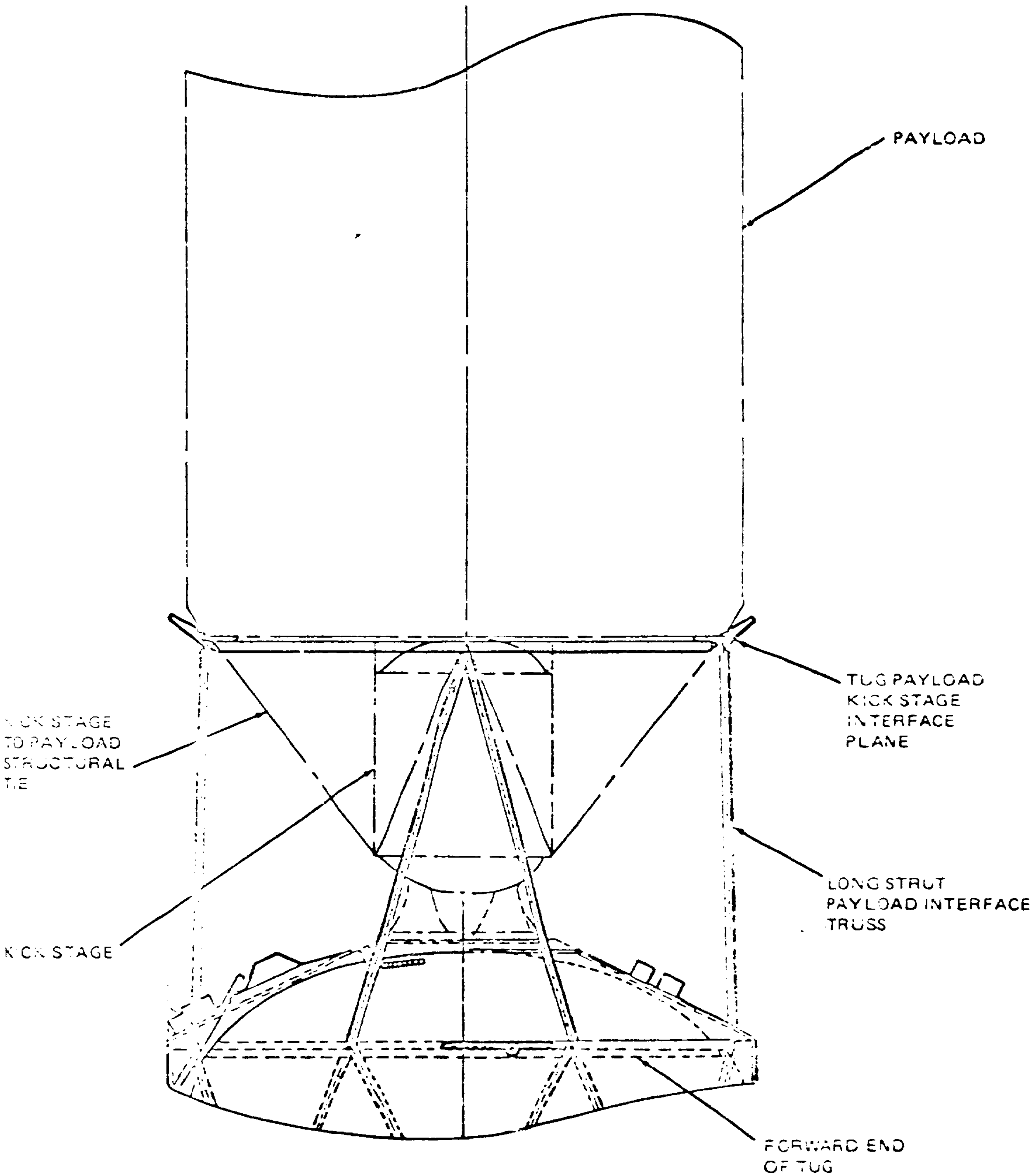
PAYLOAD
TUG PAYLOAD
KICK STAGE
INTERFACE
PLANE
KICK STAGE
TO PAYLOAD
STRUCTURAL
TIE
LONG STRUT
PAYLOAD INTERFACE
TRUSS
KICK STAGE
FORWARD END
OF TUG

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Table 2-6

OPTION 2
WEIGHT STATEMENT FOR RETRIEVAL MISSION

		(lb)		
Structure		2,115		
Fuel Tank and Supports			507	
LO_2 Tank and Supports			266	
Body Structure			999	
Shell				8
Supports				1
Thrust Structure			113	
Meteoroid Protection			0	
Payload Interface			230	
Thermal Protection		308		
Fuel Tank Insulation			130	
LO_2 Tank Insulation			82	
Insulation Purge			93	
Control System			3	
Avionics		1,239		
Data Management			255	
Guidance and Control			80	
Communication			152	
Instrumentation			219	
Electrical Power Source			272	
Power Distribution and Control			99	
Equipment Thermal Control			162	
Propulsion		1,330		
Main Engine			476	
Main Engine Support			625	
ACPS Engine			78	
ACPS Engine Support			151	
Dry Weight	4,992			
Contingency		499		
Margin		129		
Total Dry Weight	5,620			
Residuals		810		
Burnout Weight	6,430			
Usable Propellant			55,932	
ACPS			221	
Miscellaneous			537	
In-flight Losses		56,690		

Table 2-6

OPTION 2
WEIGHT STATEMENT FOR RETRIEVAL MISSION (Continued)

		(lb)
Orbiter Launch Weight	63,120	
Orbiter Interface - Cargo Bay		1,510
Orbiter Interface - Remaining		270
Miscellaneous		100
Ground Launch Weight	65,000	

Tug Mass Fraction = 0.886

2.9.2 Center of Gravity

Figure 2-10 illustrates the three selected mission points for Orbiter center of-gravity landing constraints for both deployment and retrieval missions. The only center of gravity outside these limits is a retrieval mission with fully loaded Tug plus interface provisions. This center-of-gravity constraint is applicable during abort for subsonic and hypersonic flight and is met by dumping approximately 20 percent of the LO_2 propellant during Shuttle engine burn with the remaining LO_2 dumped 30 sec after main engine cutoff (M
The abort summary and analysis are included in Volume 6, Sections 5 and 6.

2.10 RELIABILITY SUMMARY

The same reliability design requirements were used to evolve all Tug config options. The first was to ensure a minimum reliability of 0.97 for the ove Tug system; the second was to ensure all subsystems met the defined failure tolerance criteria; i.e., they were fail-safe as a minimum and fail-operati fail-safe for critical functions. These two requirements are met by the Option II configuration for the single-stage Tug and for the augmented Tug. Table 2-7 summarizes the major subsystem reliabilities and the associated redundancy level necessary to meet the failure tolerance criteria and syste reliability requirement.

A complete definition of the failure tolerance criteria and the compliance each Option 2 subsystem are contained in Volume 5, Section 6. Essentially, criteria are defined so that no single Tug failure may result in a hazard which jeopardizes the flight or ground crews.

The subsystem and system reliability prediction used standard methodology. nominal environmental adjustment factors (K-factors) and mission phase dura used are given in Table 2-8. The reliability calculations were based on:

$$R = 1 - \sum_{i=1}^{n} \lambda_i \; N_i \; T_i$$

where there are n items in the system, N of the ith item, and the failure r (λ) is adjusted as shown in the detail assessment sheets of Volume 5, Section 6

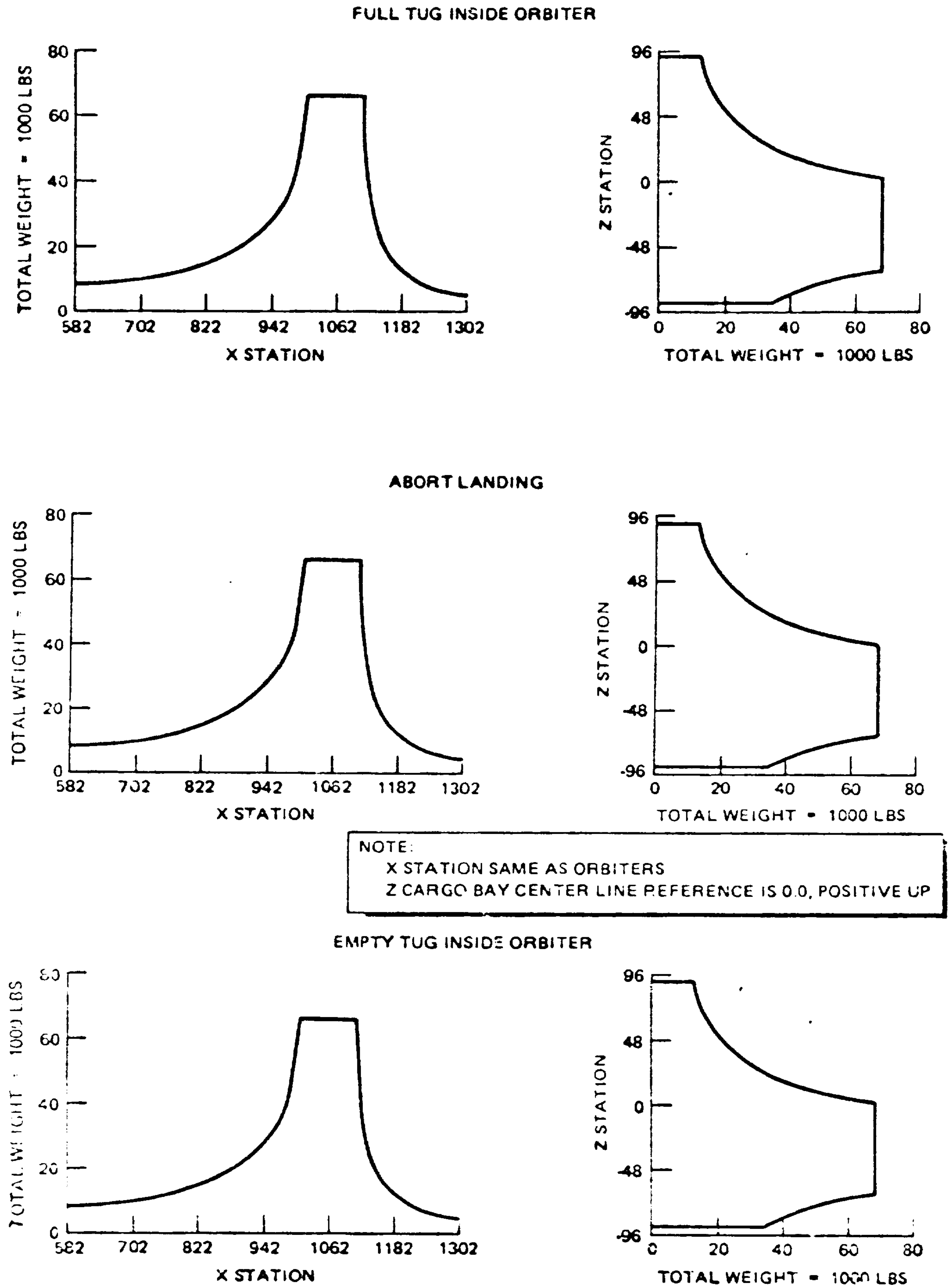


Figure 2-10. Orbiter Center-of-Gravity, Option 2

Table 2-7

REDUNDANCY SUMMARY - OPTION 2

Subsystem/Reliability	Redundancy Level
Structures (0.999999)	None - Design per MSFC HDBK 505
Propulsion (0.986785)	
Main Engine	None - Fail-safe shutdown. Redundant feed shutoff valves provided in the support system
Main Engine Support System	Component - Fail-safe shutdown
ACPS	Component - Fail-operational/fail-sa[illegible] for critical functions
Thermal Control	None — Not critical per failure tolerance criteria
Avionics (0.995677)	Component - Except for the GNC laser radar and TVC battery which are not critical to orbit safety
Interface Systems (0.999807)	
Payload Separation	None - Fail-safe
Tug-OSS Separation	None - Fail-safe (Crew EVA action not included)

Total Reliability Single Stage (0.982268 for 144-hr mission)

Table 2-8

TIME/K-FACTOR SUMMARY

Mission Phase	Duration (Hours)	K-Factor
Launch and Boost	1/4	15
In Orbiter Bay (coast)	24	
Tug Coast	Mission-dependent	1
Tug Engine Burn	1/2	[illegible]
Reentry	1/4	[illegible]
Nonoperating	Mission-dependent	[illegible]

Redundancy selection considered the system reliability requirement, weight, and cost implications. Redundant items were added sequentially in order of the largest reliability improvement per pound of added weight. Table 2-9 shows the reliability/weight relationships.

Considering the Burner II with a reliability of 0.982 as representative of a kick stage, the Tug system reliability as obtained from Figure 2-11 is 0.9717 with augmentation and 0.9823 for a Tug free flight of 144 hours.

2.11 SYSTEM SAFETY

This Tug, when designed, produced, and operated under the constraints of its criteria and requirements, will from a safety standpoint, provide the Government with a vehicle well within an acceptable risk level for the Space Shuttle program. The following features should be incorporated.

2.11.1 Design

A. Burst discs and relief valves in the ACPS, pneumatic supply system, ambient helium system, and the tank purge system. These systems will vent to the Tug overboard vent system.

B. Relief valves on the insulation purge bags.

C. Separate shutoff valves for the GHe supply to the purge bags to preclude cross-flow of leaked propellants through the system.

D. Single-point failure of thruster chamber valve identified either by leakage or inadvertent operation. Valve design selection changed to provide two series valves, one normally closed and the other capable of latching in either the open or closed position.

E. Identified system inhibit and override functions.

2.11.2 Production

A. Established leak rate levels of GHe for H_2 system tests.

B. Preliminary analyses of refurbishment concepts to ensure identificatio of hazardous functions and to reduce exposure to the hazards; i.e.,

Table 2-9

OPTION 2: RELIABILITY/WEIGHT SUMMARY

144 HOUR MISSION; ROUND TRIP; BASELINE R = 0.7718

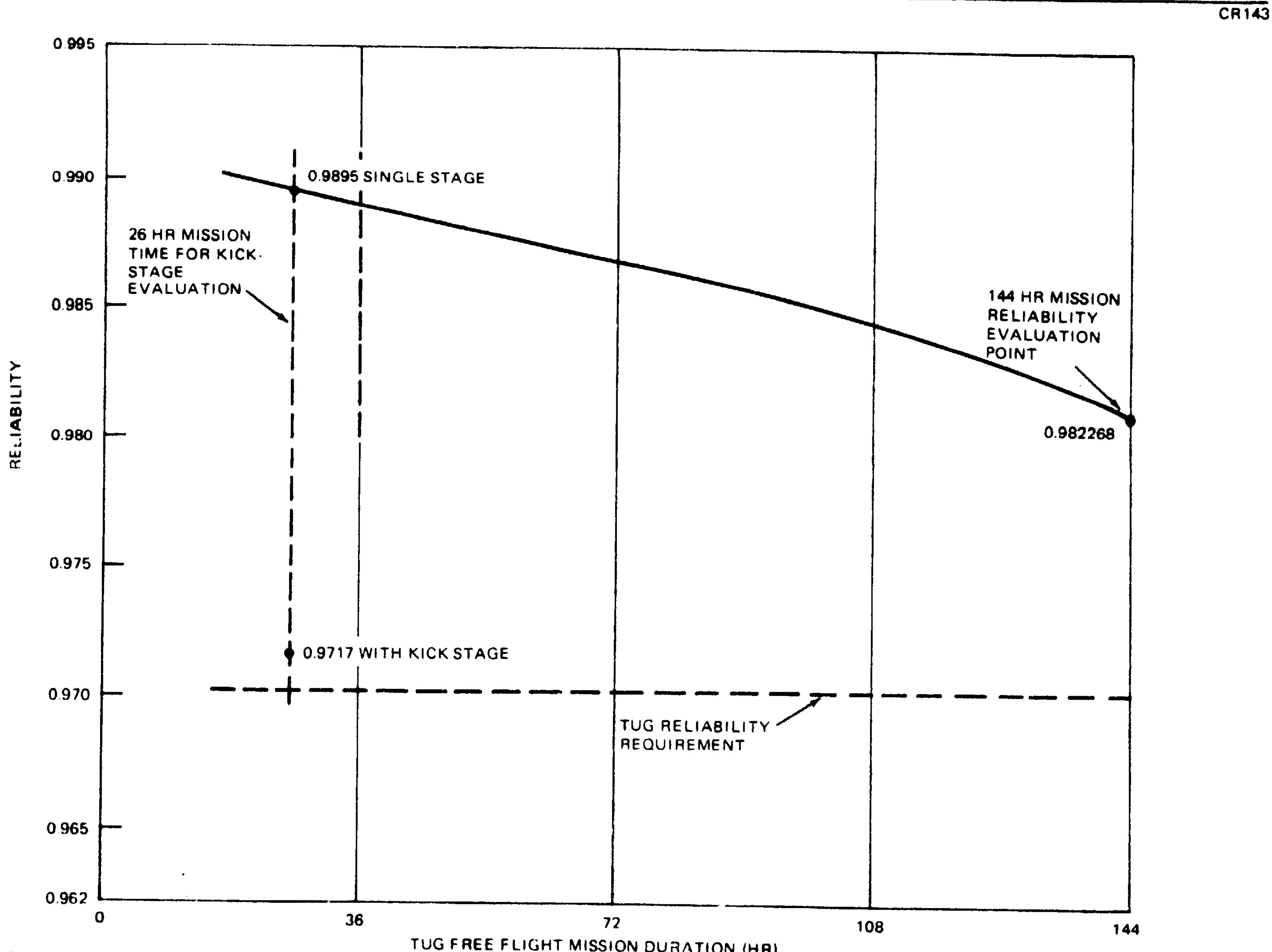
No. Items in System	No. Redundant	Nomenclature	Total Δ Weight in Lb	Increase in R per Lb Wt	Redu Syst
6	3	Inertial Measurement Unit	10	0.0063	0.8
40	20	Power Distribution	10	0.0015	0.8
6	3	ACPS Press Transducer	3	0.0012	0.8
2	1	Computer/DCU (Plus Internally Redundant SCU)	26	0.0010	0.8
8	4	ACPS Temperature	2	0.0009	0.8
2	1	Remote Data Processor	11	0.0007	0.8
2	1	Star Sensor	10	0.00045	0.8
2	1	Inst and Software	100	0.0003	0.9
12	6	Module Int Unit Components	160	0.0002	0.9
2	1	Tape Recorder	20	0.0002	0.9
12	6	Comm Components	45	0.0002	0.9
2	1	Fuel Cell	45	0.0001	0.9
2	1	Orbiter Elect Interface	20	0.00007	0.9

toxic vapors, testing pressurized systems at levels acceptable for personnel exposure.

C. Preliminary analyses of the proposed materials and the fabricat methods show no new hazards.

2.11.3 Operations

A. Preliminary analyses of operational concepts to ensure identifi or hazardous operations and sequencing those operations to redu exposure to these hazardous operations; i.e., pressurization of



gure 2-11. Reliability vs Mission Time (Option 2)

pressure vessels with a 2 to 1 design ratio to a level not to exceed 4 to 1 when operational personnel are exposed; restraints storable propellant loading and detanking, etc.

B. Items for crew warning and caution monitoring, hazard potentials at the tilt table interface, and at the Tug-Orbiter hard points.

C. The established quantity of GH_2 to be dumped below 110,000 ft on reentry.

D. Toxicity levels for hydrazine and requirements for monitoring af the monopropellant system is filled.

E. Results of hazards analyses related to abort and post-landing recovery.

F. Results of calculations to determine impact of fluids on the orb bay. These calculations are shown in Volume 7, Tables 5-1 thru

2.11.4 Residual Hazards and Rationale for Acceptance

The residual hazards identified to date are corrosion, fire, explosion, pressure, and toxicity. The materials or situations which fit into any of these categories are identified and the rationale for acceptance given in Table 2-10.

Table 2-10

RESIDUAL HAZARDS

Source	Location
	Corrosion
Monomethyl Hydrazine	ACPS
Nitrogen Tetroxide	ACPS
	Fire
Hydrogen	LH_2 Tank Fuel Cells
Monomethyl Hydrazine	ACPS
Thermal Insulation	Encapsulates Tanks
Wiring Insulation	General
Bonding Resins	General

Table 2-10

RESIDUAL HAZARDS (Continued)

Source	Location
Explosion	
Hydrogen	LH_2 Tank and Batteries
Monomethyl Hydrazine	ACPS
Pressure	Propellant Tanks, Pressurization
H_2	and Pneumatics Purge System and ACPS
O_2	
GH_e	
Toxicity	
GN_2	Pressurant
GH_2	Propellant
GH_e	Purge
MMH	ACPS
N_2O_4	ACPS

The analyses and rationale for acceptance of each of these hazards is discussed in detail in Volume 7.

Section 3
PERFORMANCE AND CAPABILITIES

3.1 SYSTEM PERFORMANCE SUMMARY

3.1.1 Mission Performance

The performance capability was computed for each mission in the mission mo and for each mission mode -- deploy, retrieve, round trip, and expendable. Table 3-1 summarizes the general mission descriptions. The performance re are given in Table 3-2. A discussion of the derivation and application of these data is presented in Volume 4, Sections 1.1, 1.4, and 1.5.

3.1.2 Performance Envelope

The parametric performance capabilities (payload versus velocity curves) a presented in Figures 3-1 through 3-3 for 28.5, 55, and 90 deg inclinations respectively. Additional details of the inputs and applications of these are given in Volume 4, Sections 1.1, 1.3, and 1.4. The numbered diamonds indicate the performance requirements for each mission.

3.2 MISSION CAPTURE

Missions for Option 2 commence from ETR in 1984 and from WTR in 1985. The total number of payloads scheduled for deployment by this option is 258 an for retrieval is 179. Since some deployment missions carry multiple paylo only 226 total missions are required. The configuration is potentially capable of accomplishing all of the missions identified. The availability the Tug in 1984 due to normal program buildup constraints limits Tug flight to 20. To effectively use this launch rate in 1984, flights were centered ETR and were concentrated on reusable deployment missions.

Table 3-1

MISSION DESCRIPTIONS

Mission No.	$H_a \times H_p$ (nmi)	Inclination (deg)	Remarks
1-8	19,323	0	Synchronous orbit - single-burn tra fer orbit injection
1-8A	19,323	0	Synchronous orbit - two-burn transf injection
1-8B	19,323	0	Synchronous orbit - two-burn transf injection with 600 fps for multiple payload deployments
9	1AU	Ecliptic	
10	6,900	55	
10A	6,900	55	Alternate - Shuttle launched into 28.5 deg
11	1,600 x 30,000	20	
12	180 x 1,800	90	
13	1,000 x 20,000	90	
13A	1,000 x 20,000	90	ETR Alternate - Shuttle launched in 28.5 deg
13B	1,000 x 20,000	90	ETR Alternate - Shuttle launched in 55 deg
14	300 x 3,000	90	
15	700	100	
16	500	99.2	
17- 8	Interplanetary		ΔV - 13,000 fps
19			16,500
20			23,000
21-2			24,000
23			18,400
24			22,000

Table 3-1

MISSION DESCRIPTIONS (Continued)

Mission No.	$H_a \times H_p$ (nmi)	Inclination (deg)	Remarks
D11	58,000	0,30,60	
D10	860 x 21,000	63.4	Shuttle launch into 63.4 deg (WTR)
D10A	860 x 21,000	63.4	ETR Alternate - Shuttle launched into 55 deg
D5	750	99	
D3	13,600 x 25,000	60	Shuttle launched into 60 deg (WTR)
D3A	13,600 x 25,000	60	ETR Alternate - Shuttle launched into 55 deg
D12	300	104	
D16	400	98.3	

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Table 5-2

PERFORMANCE RESULTS

Configuration Option 2 Stage Wt=6430.00 lb ISP=459.20 sec DEL ISP=4.00

Mission	Gross-Wt V-Out	PL-Round V-Back	PL-Deploy	PL-Retrieve	PL-Expend
1-8	62665.00 13972.00	2900.97 13920.00	7504.50	4729.05	17708.20
1-8A	62665.00 13890.00	2953.36 13920.00	7640.02	4814.46	17843.73
1-8B	62665.00 14190.00	2576.71 14220.00	6303.62	4147.47	17351.56
9	62665.00 14160.00	2515.42 14350.00	6701.01	4027.12	17400.33
10	50665.00 9700.00	7041.39 9700.00	13656.17	14539.03	19695.72
10A	62665.00 12760.00	4541.49 12760.00	10853.71	7808.99	19790.77
11	62665.00 12450.00	5015.93 12450.00	11736.50	8759.61	20351.70
12	32665.00 2285.00	17479.28 2285.00	20430.62	121000.06	21516.32
13	32665.00 8400.00	3942.95 8400.00	6996.99	9033.53	11977.40
13A	62665.00 13460.00	3541.27 13460.00	8877.61	5891.30	18566.99
13B	50665.00 11200.00	4546.61 11200.00	9768.05	8505.62	17152.41
14	32665.00 3600.00	13549.12 3600.00	17324.65	62172.59	19116.39
15	26665.00 1700.00	14710.73 1700.00	16521.33	134232.19	17312.73
16	26665.00 1120.00	16453.28 1120.00	17760.87	223484.31	18271.88
17-8	62665.00 13140.00	3903.72 13250.00	9659.28	6565.52	19119.18
19	62665.00 16740.00	.00 17210.00	.00	.00	13551.32

Table 5-2

PERFORMANCE RESULTS (Continued)

Configuration Option 2 Stage Wt=6430.00 lb ISP=459.20 sec DEL ISP=4.00

Mission	Gross-Wt V-Out	PL-Round V-Back	PL-Deploy	PL-Retrieve	PL-Expend
20	62665.00 23550.00	.00 24500.00	.00	.00	6121.14
21-2	62665.00 24600.00	.00 25500.00	.00	.00	5252.79
23	62665.00 18720.00	.00 19550.00	.00	.00	11024.61
24	62665.00 22500.00	.00 23500.00	.00	.00	7054.02
D11	62665.00 13930.00	2921.38 13930.00	7562.46	4760.28	17777.53
D10	48665.00 8500.00	8814.24 8500.00	15748.55	20018.09	20807.13
D10A	50665.00 9800.00	6859.16 9800.00	13392.96	14059.91	19517.94
D5	26665.00 1770.00	14509.61 1770.00	16373.53	127459.19	17199.53
D3	48665.00 11850.00	3217.77 11850.00	7226.88	5800.43	15238.16
D3A	50665.00 11920.00	3518.71 11920.00	7940.63	6318.73	16021.10
D12	26665.00 500.00	18475.09 500.00	19116.72	550454.06	19340.03
D16	26665.00 850.00	17312.75 850.00	18347.27	307044.75	18731.49

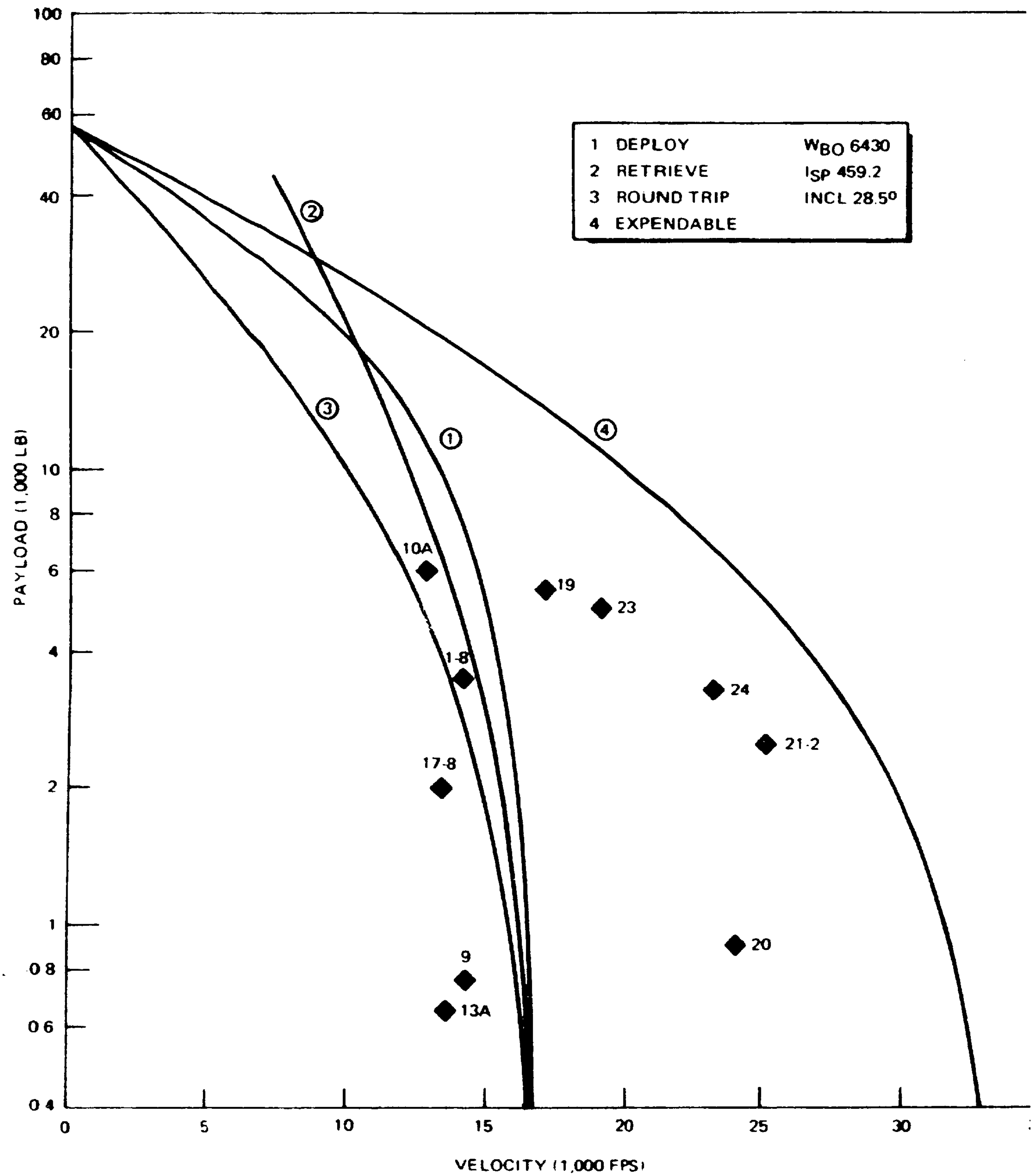


Figure 3.1 Performance Capability Configuration Opt 2

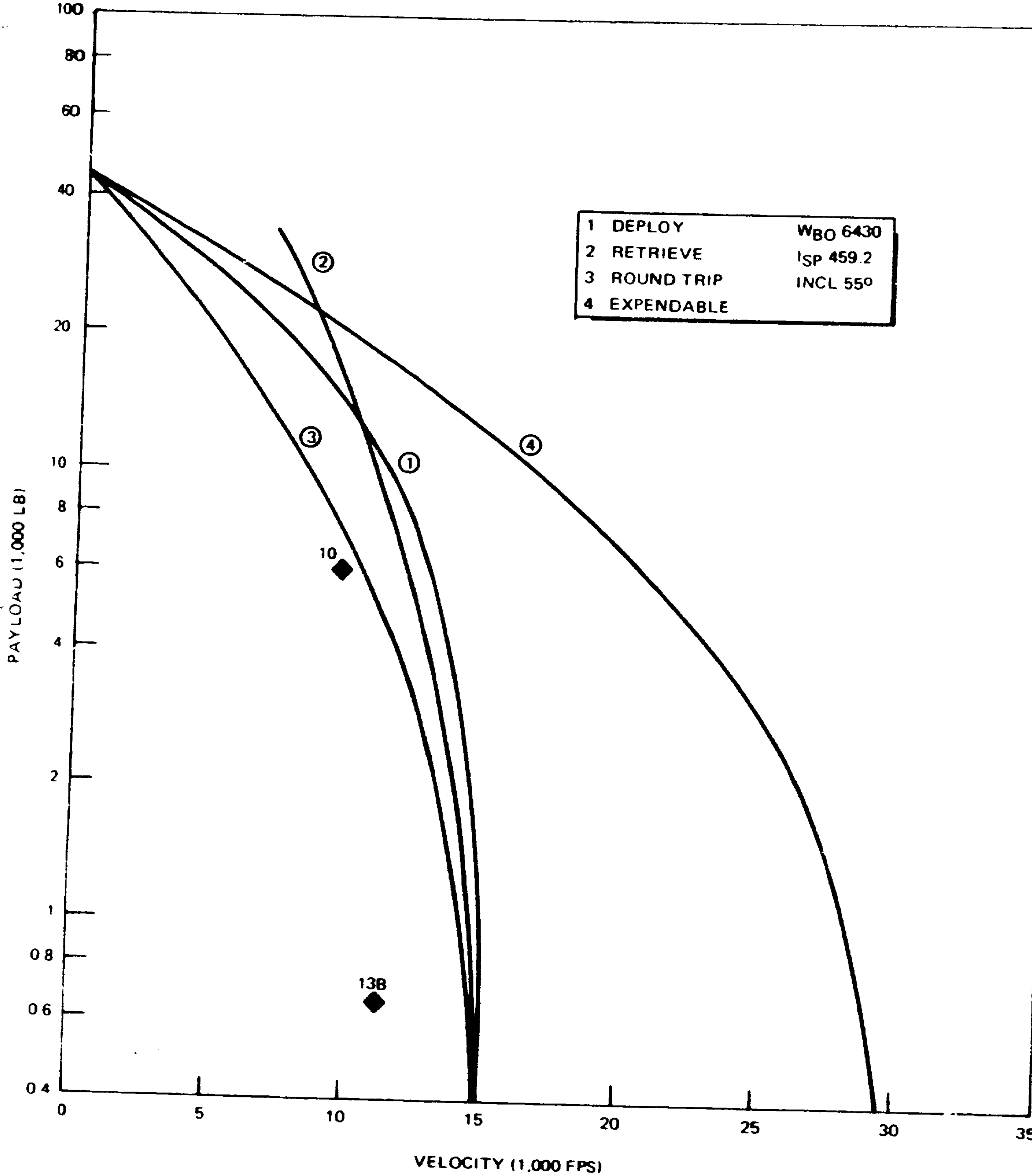
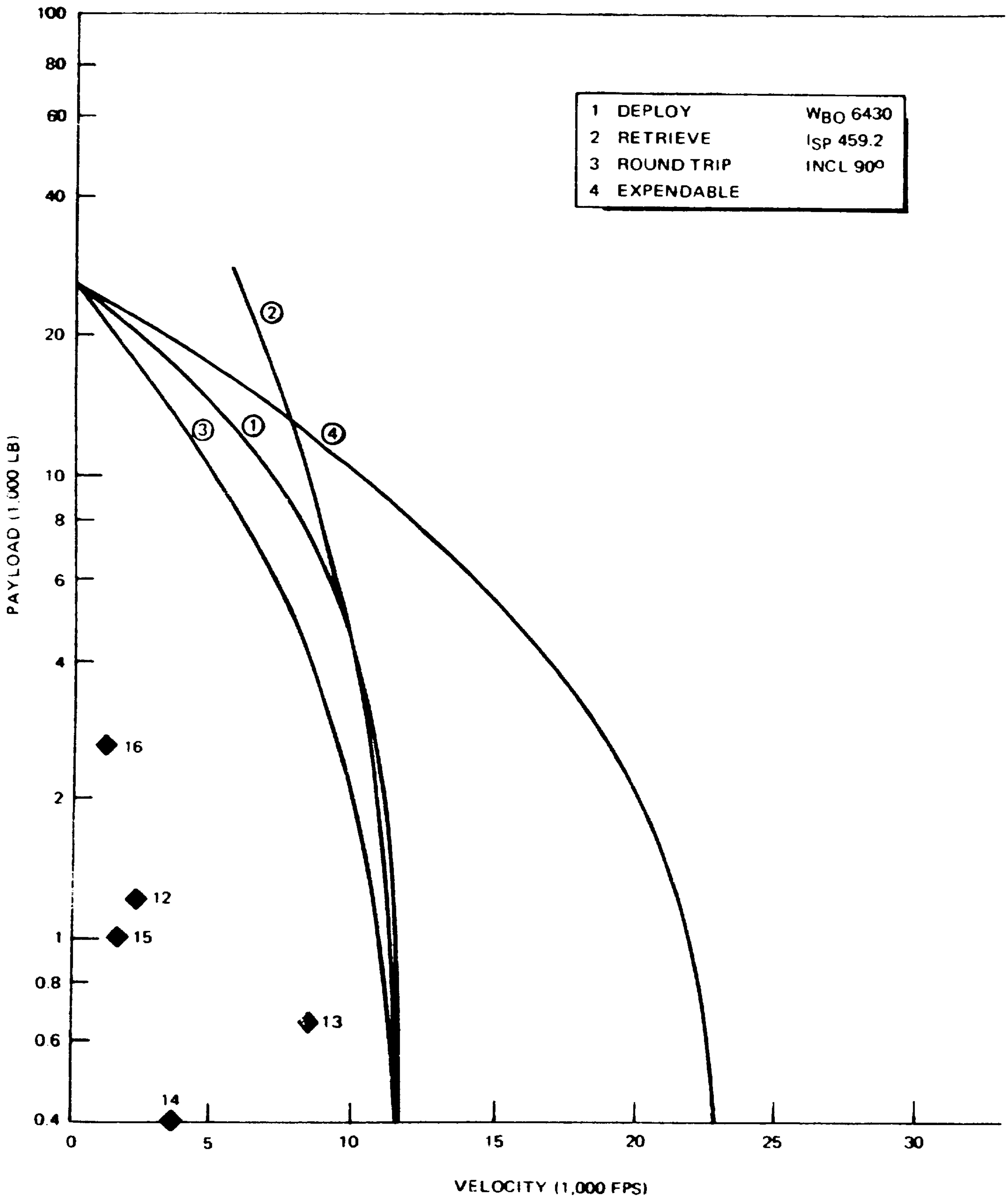


Figure 3-2. Performance Capability Configuration Opt 2



1 DEPLOY
2 RETRIEVE
3 ROUND TRIP
4 EXPENDABLE
W_BO 6430
I_SP 459.2
INCL 90°
PAYLOAD (1,000 LB)
VELOCITY (1,000 FPS)
100
80
60
40
20
10
8
6
4
2
1
0.8
0.6
0.4
0
5
10
15
20
25
30
16
12
15
13
14

The flight modes utilized by this option over its 7-year operational period include the following:

A. Basic Tug - reusable (deployment and retrieval)

B. Basic Tug - expendable (deployment)

C. Basic Tug plus Polaris class auxiliary stage (deployment)

D. Basic Tug - dedicated mode

E. Basic Tug - reusable multiple mission (multi-deployment/single retrieval)

The scope of the flight operations to accomplish the necessary missions include a total of 225 launches divided as follows:

A. NASA Mission Launches
   1. ETR 88
   2. WTR 29

B. DOD Mission Launches
   1. ETR 89
   2. WTR 16

C. Three reflights required to accommodate mission losses due to failures.

The annual launch rate is summarized in the accompanying flight schedules, Tables 3-3 through 3-7, for NASA and DOD and for ETR and WTR.

3.3 FLEET SIZE

The fleet size requirements for this program option result from two primary considerations: (1) the number of missions performed in the expendable mode and (2) the number of Tugs required to perform the last year of operations. The first parameter is a function of the capture analysis, while the second is a result of launch-to-launch cycle time.

A candidate usage and Tug introduction schedule is presented in Table 3-8.

Table 3-3

FLIGHT SCHEDULE

TUG CONCEPT OPTION 2

LAUNCH SITE ETR/WTR AGENCY NASA/DOD

COMPANY MDAC

	79	80	81	82	83	84	85	86	87	88	89	90	Total
Tug (Basic)**						20	32	(1) 36	(1) 37	31	(3) 33	(1) 36	(6) 225
Auxiliary Stage								(3)	(2)				(5)
Drop Tanks													
(Other)				1*									1
Shuttle**				1*		20	32	36	37	31	33	36	226

() Denotes number expended.

Remarks: 25 payloads not accommodated in 1984 due to Tug availability

* Interface Verification Unit (IVU) test flight

** Includes reflights due to reliability losses

Table 3-4

FLIGHT SCHEDULE

TUG CONCEPT OPTION 2

LAUNCH SITE ETR AGENCY NASA

COMPANY MDAC

	79	80	81	82	83	84	85	86	87	88	89	90	Total
Tug (Basic)						10	14	(1) 14	(1) 14	9	(3) 14	(1) 13	(6) 88
Auxiliary Stage								(3)	(2)				(5)
Drop Tanks													
(Other)				1*									1
Shuttle				1*		10	14	14	14	9	14	13	89

() Denotes number expended.

Remarks: 8 payloads not accommodated in 1984 due to Tug availability

* IVU test flight

Table 3-5

FLIGHT SCHEDULE

TUG CONCEPT OPTION 2

LAUNCH SITE ETR AGENCY DOD

COMPANY MDAC

	79	80	81	82	83	84	85	86	87	88	89	90	Total
Tug (Basic)						10	10	12	15	15	10	17	89
Auxiliary Stage													
Drop Tanks													
(Other)													
Shuttle						10	10	12	15	15	10	17	89

() Denotes number expended.

Remarks: 8 payloads not accommodated in 1984 due to Tug availability

Table 3-6

FLIGHT SCHEDULE

TUG CONCEPT OPTION 2

LAUNCH SITE WTR AGENCY NASA

COMPANY MDAC

	79	80	81	82	83	84	85	86	87	88	89	90	Total
Tug (Basic)							6	4	6	4	5	4	29
Auxiliary Stage													
Drop Tanks													
(Other)													
Shuttle							6	4	6	4	5	4	29

( ) Denotes number expended.

Remarks: 6 payloads not accommodated in 1984 due to Tug availability

Table 3-1

FLIGHT SCHEDULE

TUG CONCEPT OPTION 2

LAUNCH SITE WTR AGENCY DOD

COMPANY MDAC

	79	80	81	82	83	84	85	86	87	88	89	90	Total
Tug (Basic)							2	5	2	2	4	1	16
Auxiliary Stage													
Drop Tanks													
(Other)													
Shuttle							2	5	2	2	4	1	16

( ) Denotes number expended.

Remarks: 3 payloads not accommodated in 1984 due to Tug availability

Table 3-8

EQUAL USAGE SCHEDULE -- OPTION 2

		80	81	82	83	84	85	86	87	88	89	90	Total
Number of Flights						20	32	35	37	30	33	35	222
Number of Expended Tugs								(1)	(1)		(3)	(1)	(6)
Tug ID	1					8	11	5					24
	2					7	11	4	2				24
	3					5	4	4	7	2	2		24
	4						6	7	7	2	2		24
	5							10	8	3	4		25
	6							5	7	4	4	6	26
	7								3	4	7	11	25
	8								3	7	6	9	25
	9									8	8	9	25
Reflights/ Losses								1		1		1	3

At the top of Table 3-8, the number of flights per year is shown and the nu of Tug expendable flights. The number of Tugs required were established by first determining the number of Tugs necessary to accomplish the 1990 requi ments and working backward from that point. The maximum number of flights Tug can perform in a year is established first by summing the Tug ground turnaround time and the mission time which results in the minimum mission t around time. In Option 2 the ground turnaround time is 27.9 days and the average mission time is 3.3 days. The mission turnaround time is thus 31.2 The maximum number of cycles (flights) in a year is then 11.

Using this number and assuming that the maximum number of flights that an expended Tug can make in the year that it is expended is six (one-half the maximum turnaround in a year), the fleet of four for 1990 is established. Working backward from there, it can be seen that in 1989 the three expendabl requirements and those necessary in 1990 make up the inventory requirements. The resulting data show that to carry out the operations, a total of nine Tu are required during the program. Using the Government ground rules for reliability losses, three additional vehicles are required. Thus, the total size necessary is 12, of which 2 are required at IOC.

Section 4

OPERATIONS

4.1 FLIGHT OPERATIONS

The work breakdown structure for the Tug Study divides the flight operations into four areas or blocks; namely, Mission Planning, Flight Control, Flight Evaluation, and Flight Support Software.

The methodology for deriving the manpower requirements for each of these is presented in Volume 6.

Option 2 consists of a configuration with an autonomy level (III), a mission duration (6 days), a 7-year program, and incorporates rendezvous, docking, and payload spinup capabilities. The appropriate factors for these features plus the number of flights and mission times were inserted into the computer program and the resulting manloads were obtained.

These are presented in Tables 4-1 and 4-2 and Figures 4-1 and 4-2.

4.2 GROUND AND LAUNCH OPERATIONS

The results of the ground and launch operations analysis include the detailed definition of all ground and launch operations activities, equipment, manpower and schedules at both the Eastern Test Range (KSC) and Western Test Range (VAFB) which are required to support both NASA and DOD Tug missions.

The overall study/program objectives which related to the ground and launch operations are:

- Low-cost development and operation.
- Reusable Tug capable of operating throughout the program duration with refurbishment/replacement of life-limited components as required.
- A minimum reliability goal for the Tug of 0.97.

Table 4-1

MAN-LOADS (NASA ONLY)

Option	=	2

Total Program Costs

Number of Flights	=	117.0
Autonomy Level	=	3.0

NASA Mission

Launch from WTR	=	29.0
Launch from ETR	=	88.0

Flight Operations Recurring Costs (NASA Only)

		Manhours	Computer Hours	Costs
Mission planning	=	257817.6	2122.4	5969213
Flight control	=	341692.5	5974.7	9122164
Flight evaluation	=	259308.0	2658.8	6204461
Flight software	=	85881.8	1195.1	2604765
Unused manhours	=	9466.9	0.0	189338
Total Operations, Hours	=	858818.0	11950.9	
Total Operations, Costs	=	19323405.7	4577199.2	23900604
Operations per/flt costs	=	204278.7		

Flight Operations Nonrecurring Costs (Total program for both DOD and NASA)

		Manhours	Computer Hours	Costs
Mission planning	=	284254.5	1198.9	6854903
Flight control	=	25084.8	0.0	564408
Flight evaluation	=	0.0	0.0	0
Flight software	=	173151.1	2974.8	5035251
Total DDT & E Hours	=	482490.3	4173.7	
Total DDT & E Costs	=	10856032.6	1598530.3	12454562.

Table 4-2

MANLOADS (DOD ONLY)

Option = 2

Total Program Costs

Number of Flights = 105.0

Autonomy Level = 3.0

DOD Mission

Launch from WTR = 16.0

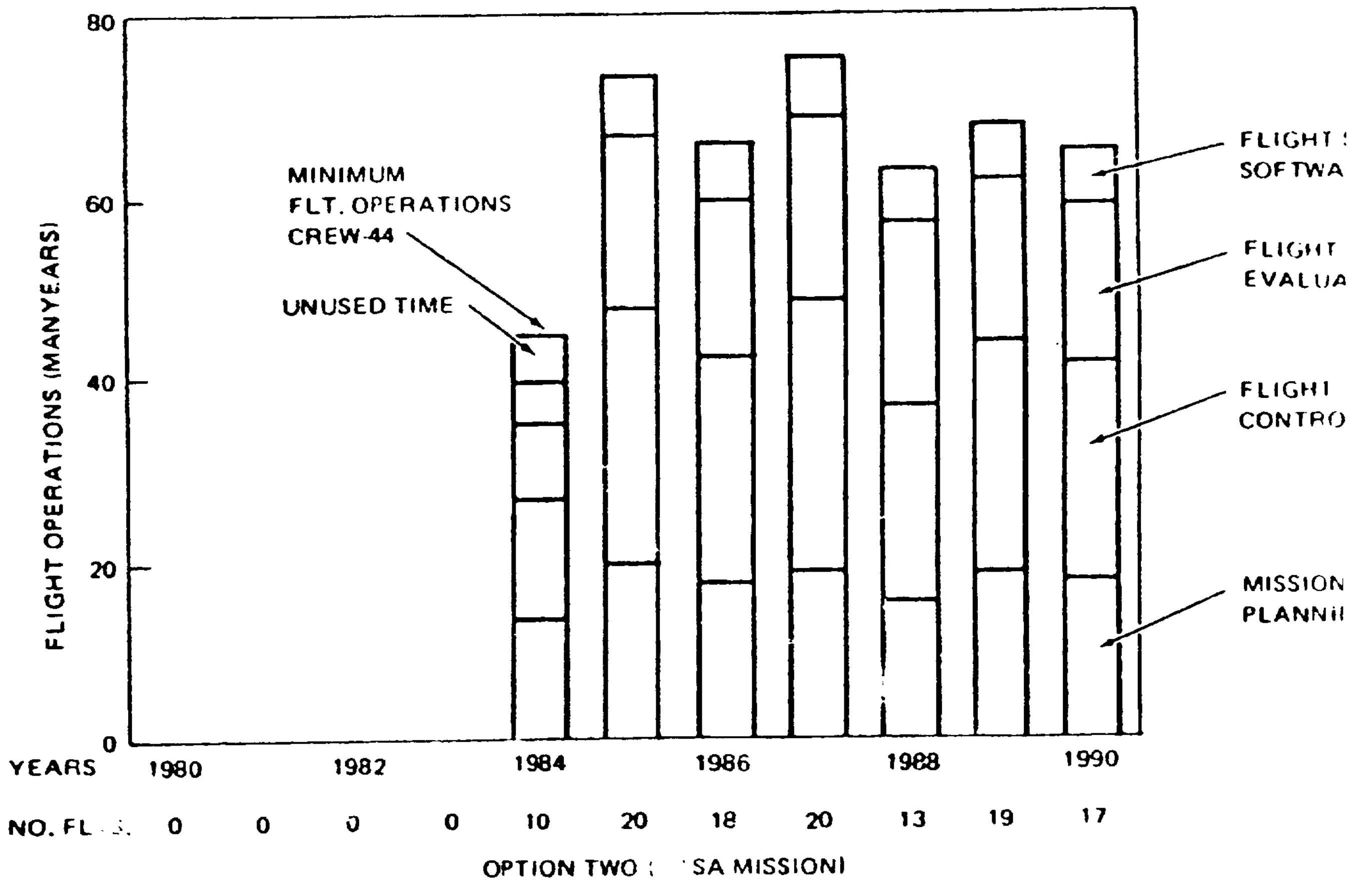
Launch from ETR = 89.0

Flight Operations Recurring Costs (DOD Only)

		Manhours	Computer Hours	Costs
Mission planning	=	246934.2	2015.7	5710682.0
Flight control	=	311005.9	5439.4	8303421.2
Flight evaluation	=	254512.4	2404.4	6011133.0
Flight software	=	81245.3	1095.5	2450707.5
Unused manhours	=	8812.0	0.0	176239.6
Total Operations, Hours	=	812452.5	10955.0	
Total Operations, Costs	=	18280182.1	4195761.6	22475943.7
Operations per/flt costs	=	214056.6		

Flight Operations Nonrecurring Costs (Total program for Both DOD and NASA)

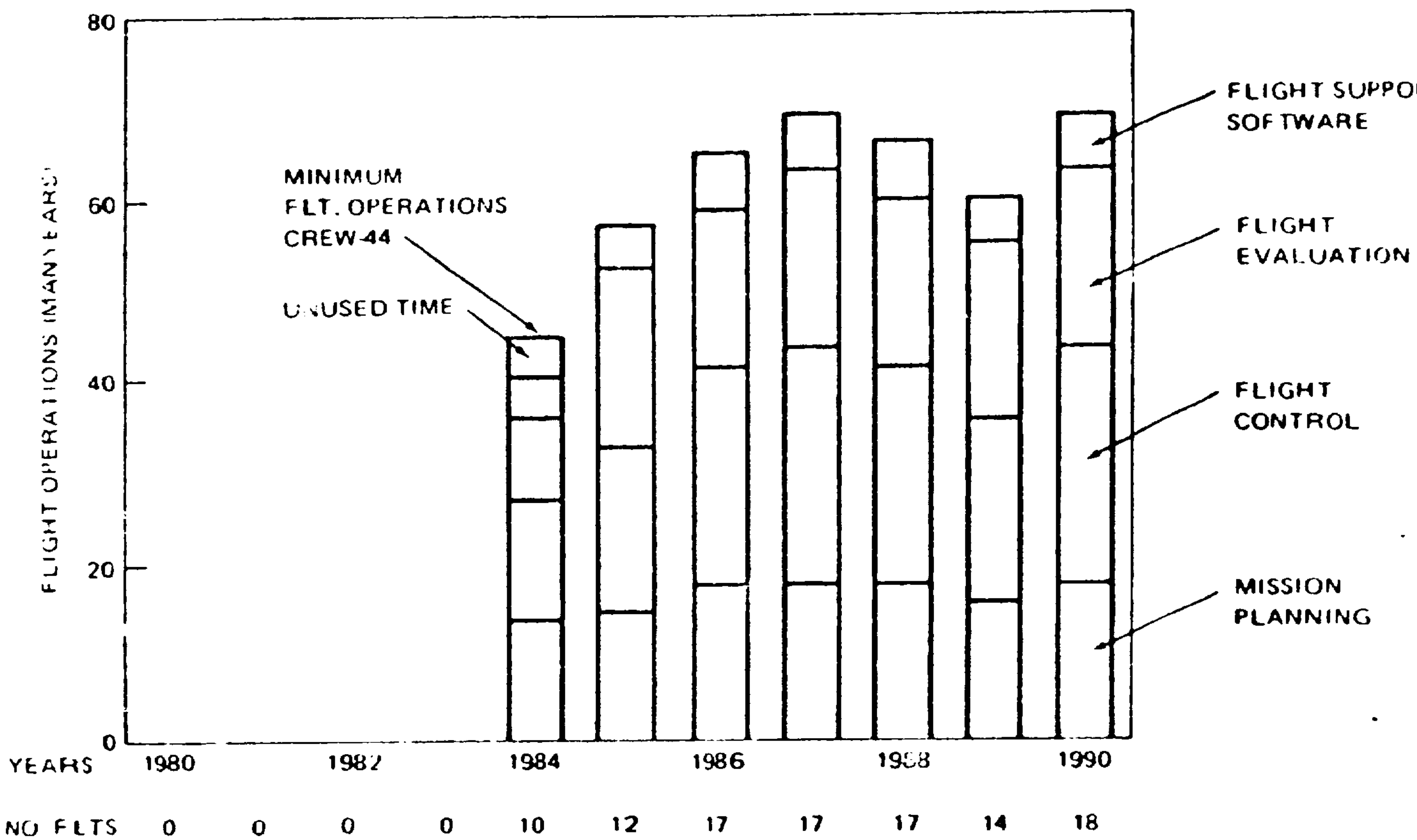
		Manhours	Computer Hours	Costs
Mission planning	=	284254.5	1198.9	6854903.2
Flight control	=	25084.8	0.0	564408.0
Flight evaluation	=	0.0	0.0	0.0
Flight software	=	173151.1	2974.8	5035251.6
Total DDT & E Hours	=	482490.3	4173.7	
Total DDT & E Costs	=	10856032.6	1598530.3	12454562.8



TOTAL MANYEARS	=	453
MISSION PLANNING	=	124
FLIGHT CONTROL	=	160
FLIGHT EVALUATION	=	124
FLIGHT SUPPORT SOFTWARE	=	40
UNU [illegible] D TIME	=	5

TOTAL FLIGHTS	=	117
WTR FLIGHTS	=	29
ETR FLIGHTS	=	88

Figure 4-1. Flight Operations Manpower Required



OPTION TWO (…OD MISSION)

TOTAL MANYEARS	=	430
MISSION PLANNING	=	119
FLIGHT CONTROL	=	146
FLIGHT EVALUATION	=	122
FLIGHT SUPPORT SOFTWARE	=	39
UNUSED TIME	=	4

TOTAL FLIGHTS	=	105
WTR FLIGHTS	=	16
ETR FLIGHTS	=	89

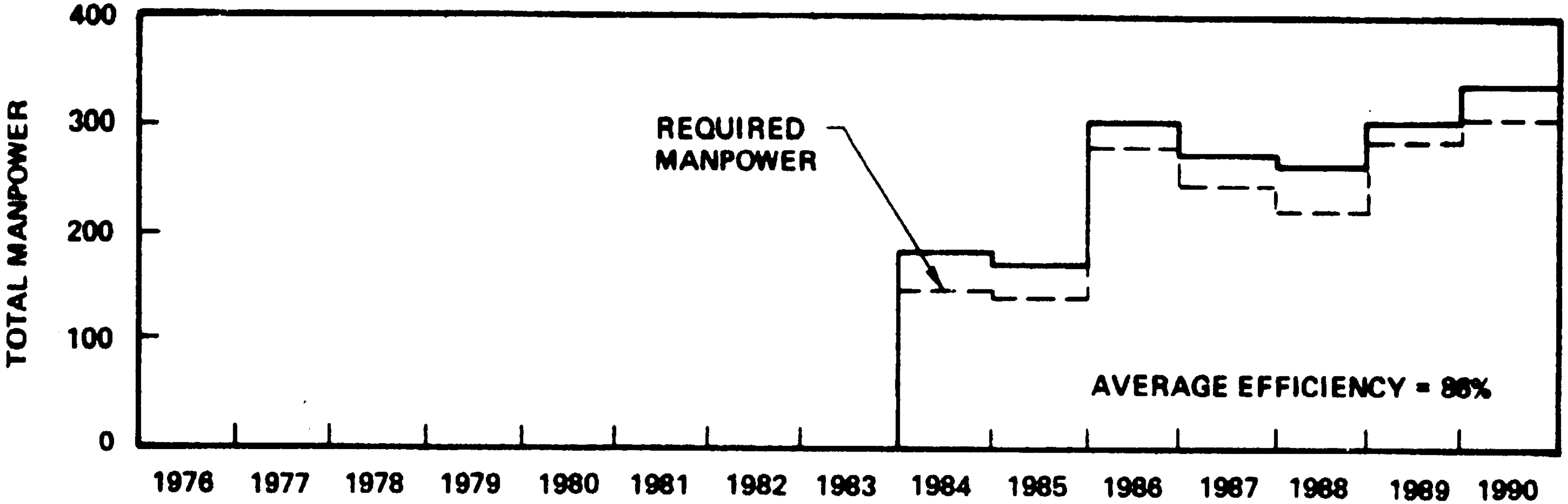
- Design for return to Earth in the Shuttle and be reused; with minimum maintenance and ground turnaround cost.
- Reducing as much as possible the maintenance and inspection of systems resulting in minimum subsystem replacements between flights

Consideration of these objectives resulted in the identification of 11 majo analyses which were evaluated to determine the required ground and launch operations resources. These analyses and the summary of results is shown b

Analysis	Result
Ground Operations Costs	ETR 53.07M; WTR 22.86M
Manning Requirements	Peak Year Manning ETR 250; WTR
Active Tug Fleet Size	ETR 3 Max 2 Min; WTR 1
Total Program Fleet Size	ETR 7; WTR 2
2-Yr IOC Delay	ETR 431 Man Year Increase - WTR 199 Man Year Increase
Operations Restrained by Shuttle	Landing to Landing +21 hours Liftoff - 144 hours to liftoff
Ground Turnaround Time	ETR 328 NASA; 341 DOD WTR 328 NASA; 328 DOD
Task Description Development	58 Functional Tasks Defined
Facility Requirements Description	Requires a new payload processi facility at ETR and WTR
GSE Description	82 types of GSE required. See Table 4-3.
Maint/Refurb/Checkout Impact on Turnaround	Maint/Refurb/Checkout requires ≈ 75 hours

Additional manpower and cost data are shown in Figure 4-3.

Appropriate data associated with each of these analyses and detail discussi are presented in Volume 4.



GROUND OPERATIONS	OPT 2
• TURNAROUND TIME	330 HRS
• AVERAGE MANPOWER	276
• TOTAL COST	$112.7 M
• LAUNCH SITE COSTS	$92.9 M
• OPS SUPPORT COSTS	$19.8 M
• OPS COST PER FLIGHT	$0.508 M

Figure 4-3. Ground Operations Summary, Option 2

4.3 REFURBISHMENT SUMMARY

The MDAC Space Tug Refurbishment (R) Concept minimizes these requirements while maintaining a satisfactory probability of launch-on-time and the required level of subsystem reliability to assure mission success. It is patterned after the commercial airlines on-condition-maintenance philosophy which monitors subsystem health — and thus precludes unwarranted maintenanc and refurbishment on subsystems, assemblies, and components which are functioning properly. Subsystem health is monitored by a combination of th following techniques:

- Operational instrumentation data consisting of subsystem performa measurements which are telemetered during flight via ground link.
- When the Tug is out of range of a ground tracking station, these data are recorded onboard for later transmission.
- Postflight/receiving inspection.
- Automated subsystem checkout (ground) of those performance charac- teristics not readily adaptable to in-flight monitoring.
- Use of onboard checkout capability for fault detection and isolat

The maintenance and refurbishment (M/R) technical approach/methodology is n sensitive to individual Tug configurations; however, the cost of an M/R cyc and depot maintenance will vary with different configurations. These variat have been expressed in the M/R inputs to the cost model for each configurat in terms of manhours/(M/R) cycle, equivalent units of production hardware f operational spares, and depot maintanence cost as a percentage of average s system hardware cost.

The maintainability analyses have evaluated unscheduled maintenance, as thi affects maintenance and refurbishment schedules, and has predicted unschedu maintenance manhours and spares requirements. These are provided in Volume In addition, the analysis has produced predictions of risk of launch with a anomaly in the Tug and risk of pad loadout as a result of anomalies discove subsequent to Tug/Shuttle mating.

The predictions are based upon a systematic analysis of the equipment operated (data management, fueling, communications, etc.) and length of operation according to the top-level functional flow diagram, and system timelines. The total risk is apportioned to risk of pad loadout or to launch unreliability on the basis of individual subsystem verification capability incorporated in the design of the Tug and Tug/Shuttle combined integrated systems test. The results of the predictions are shown in Figures 4-4 and 4-5.

4.4 GROUND SUPPORT EQUIPMENT SUMMARY

The GSE task includes the detailed definition of the GSE, quantities, price, development schedule, and GSE at each location — for factory, Eastern Test Range (KSC), and Western Test Range (VAFB) — which are required to support both NASA and DOD Tug missions. It also includes a definition of Government furnished equipment (GFE) available from the Saturn and Delta program which is usable for the Tug.

Option 2 Features:

A. GSE is sized for a fleet size of 13 vehicles for cradles, covers, and transporters.

B. New guidance and navigation checkout equipment is required.

C. New fuel cell checkout equipment is required.

D. New laser radar checkout equipment is required.

E. Factory GSE is shipped to VAFB to become launch checkout equipment for one pad. (Feasible since schedule delivery of 13 vehicles allows enough time to accomplish this.)

F. Provide only one pad of GSE at VAFB since launch rates are low from WTR and one set of hardware can support launch rate from WTR.

G. Utilizes maximum GFE from Saturn program where feasible to support KSC.

A summary of the GSE is shown in Table 4-3.

4.5 LOGISTICS SUMMARY

The MDAC Space Tug logistics concept incorporates the transportation and handling, training, inventory control, and warehousing functions, and spares.

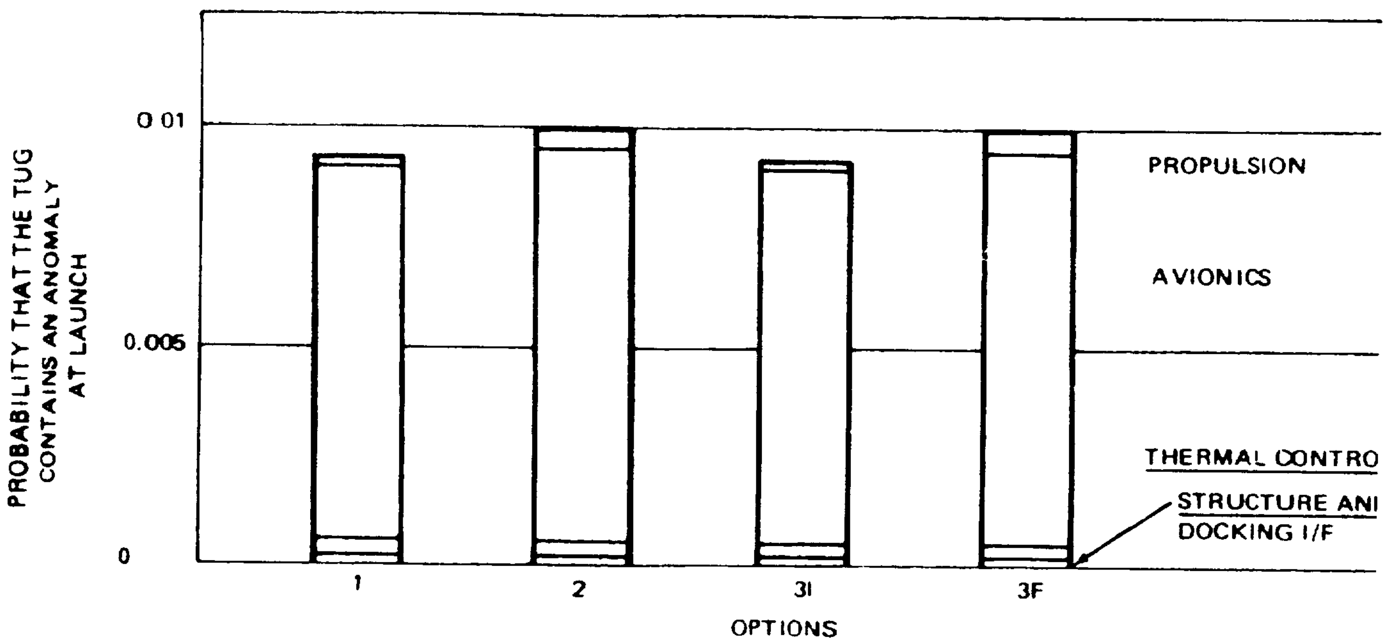


Figure 4-4. Comparisons of Tug Unreliability at Launch

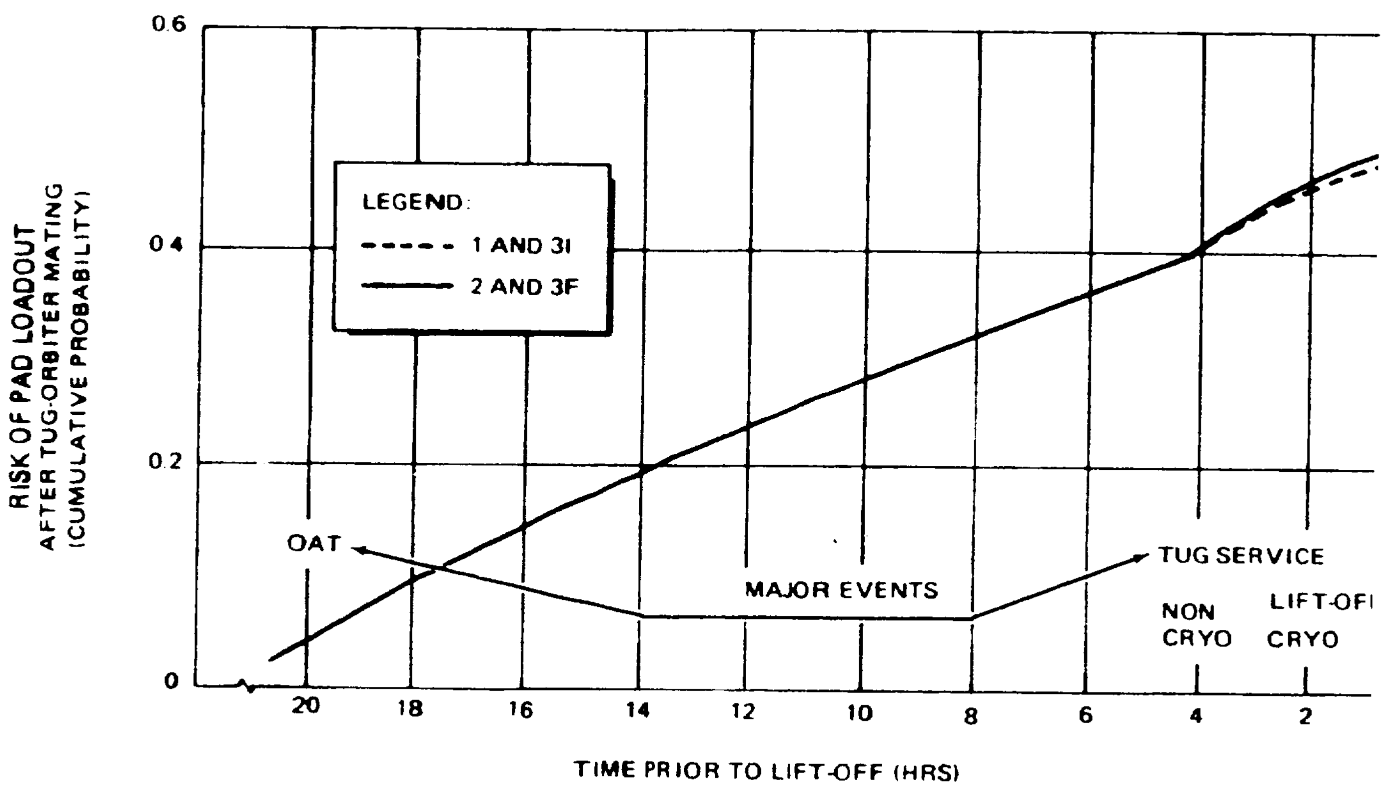


Figure 4-5. Risk of Tug Loadout Due to Prelaunch Anomaly

PROGRAM OPTION 2
GROUND SUPPORT EQUIPMENT SUMMARY

Ground Rules: Install one pad at WTR; Use GSE from factory

Number	Description	Total Units Required	Location Used: Factory	Location Used: ETR	Location Used: WTR	GFE Units
104	Air carry environmental kit -- VPG	1		1		
105	Air carry environmental kit -- VPG	1		1		
106	Air carry roller transfer kit -- VPG	2		1	1	2
107	Air carry tie-down kit -- VPG modified GFE	2		1	1	2
108	Air carry tie-down kit -- VPG	1		1		
110	Alignment kit	3		2	1	
111	APS breakout control box	3	1	1	1	
112	APS loading accessories kit	2		1	1	
1[illegible]	APS servicer	4		2	2	
115	Battery handling kit	3	1	1	1	
117	Checkout accessories kit	9	1	4	4	
118	Checkout cable kit	10	1	5	4	
119	Communications system test set	3	1	1	1	
120	Component protective covers	13	1	8	4	
121	COMSEC equipment	3		2	1	3
122	Cover -- spacecraft	13		10	3	
123	Cover -- Tug	13		10	3	
124	Cradles	13	1	9	3	
125	Cryogenic propellant loading complexes	3		2	1	1
126	Cryogenic tank trucks	2		1	1	2
127	Data management system T/S (DMST/S)	7	1	4	2	
128	Telemetry ground station	2		1	1	2
129	Digital events recorder	3	1	1	1	1
130	Engine actuator fixture	3	1	1	1	
131	Engine alignment kit	3	1	1	1	

*Factory units shipped to field centers for reuse.

GROUND SUPPORT EQUIPMENT SUMMARY

Identifier Number	Ground Rules: Install one pad at WTR; Use GSE from factory Description	Total Units Required	Location Used: Factory	ETR
132	Engine handling kit	3	1	1
133	Engine position calibration fixture	3	1	1
134	Equipment van	6	1	3
135	FM transmitter component test set	1	1	
136	Frequency calibration unit rack assembly	1	1	
137	Fuel cell checkout kit	3	1	1
139	Gas sampling equipment	6		3
140	Handling equipment	9	1	5
141	Horizon sensor tester			
142	Guidance and navigation test set	3	1	1
143	Guidance and navigation system checkout kit	3	1	1
144	Laser radar checkout and analysis kit	3	1	1
145	Launch countdown console	3		2
147	LH_2-He heat exchanger	3		2
*148	Signal conditioning unit	7	1	4
149	Orbiter simulator	3	1	1
150	Payload adapter handling kit	3		2
151	PCM/FM telemetry component test set	1	1	
152	Personnel protection equipment	8		4
153	Pneumatic console ACPS portable test set	2	1	1
*155	Power system T/S (PSTS)	7	1	4
157	Printed circuit card component test set	1		
159	Propellant utilization component test set	3	1	1
160	Propulsion component repair kit	2		1
161	Propulsion pneumatic console (checkout)	5	1	2

*Factory units shipped to field centers for reuse.

PROGRAM OPTION 2
GROUND SUPPORT EQUIPMENT SUMMARY

Number	Ground Rules: Install one pad at WTR; Use GSE from factory — Description	Total Units Required	Location Used — Factory	ETR	WTR	GFE Units
62	Pneumatic skid launch	3		2	1	
63	Propellant or pneumatic control console	7	1	4	2	
64	Battery checkout kit	2		1	1	
68	Spacecraft simulator	3	1	1	1	
69	Space tug simulator	3	1	1	1	
72	Stage transport preparation GN_2 purge unit	1		1		
73	Stage weigh and balance kit	2		1	1	
74	Star tracker simulator	3	1	1	1	
75	Static desiccant kit	7	1	4	2	
7[illegible]	Subsystem monitoring consoles	9		6	3	
77	Tape recorder component test set	3	1	1	1	
78	Television system checkout kit					
80	Environment conditioning unit	4	1	2	1	
81	Tilt table handling kit	4	1	2	1	
82	Tractor -- transporter	5	1	2	2	
83	Transporter	7	1	4	2	
84	Tug support kit (vertical)	2		1	1	
85	Umbilical system	7	1	4	2	
89	Voice and timing system	2		1	1	
90	Wide band magnetic tape recorder	5	1	2	2	
91	Workstand -- kit	12	1	6	5	
92	Security vehicle	6		3	3	
01	Simulation flight test computer programs	3	1	1	1	
0[illegible]	Ground checkout computer programs	3	1	1	1	
04	Ground checkout tug processing facility computer prog.	3	1	1	1	

*Factory units shipped to field centers for reuse.

PROGRAM OPTION 2
GROUND SUPPORT EQUIPMENT SUMMARY

Identifier Number	Ground Rules: Install one pad at WTR; Use GSE from factory Description	Total Units Required	Location Used	
			Factory	ETR
305	Ground support self-check computer programs	3	1	1
306	Launch countdown computer programs	3	1	1
307	Support software computer programs	3	1	1
308	AEDC interface cable kit	1		
309	Tug test cell holding fixture	1		
310	AEDC interface junction box	1		
311	Test software computer program	1		
312	Mission control tug subsystem software			
313	DOD mission control status & monitoring station (Totally GFE)	7		
314	NASA mission control status monitoring stations (Totally GFE)	7		

*Factory units shipped to field centers for reuse.

The primary mode of transportation between MDAC and KSC/WTR will be by Guppy-type aircraft when delivering new Tugs or when switching operational Tugs between KSC and WTR. Movement of Tug hardware (other than a complete Tug) will be accomplished via appropriate land and air modes as dictated by specific program requirements. The selection of preservation methods, packaging levels, and protective handling is based on analysis of natural and induced environments to which the hardware will be subjected during its life cycle.

4.5.1 Training

The training concept for the Tug program is based on the premise that training will be required for all ground personnel (customer and contractor) and that personnel assigned to the Tug program will already be skilled in their respective specialities; therefore, training requirements will be limited to the adaptation of their respective skills to Tug hardware and ground operations.

There will be no requirement for simulators and dedicated training equipment. Test and flight hardware, augmented by audio/visual aids, will be used. No pecial training facilities requirements are planned.

4.5.2 Inventory Control and Warehousing

The material control function includes the receiving, shipping, issue, repair, inventory control and storage of spares, repair parts and special test equipment (contractor-furnished equipment and Government-furnished equipment located at either the MDAC manufacturing facility or at the KSC/WTR launch sites. Variation in dollar value of the logistics inventory have been expressed in the maintenance and refurbishment inputs to the cost model.

4.5.3 Spares

The maintainability analyses have addressed unscheduled maintenance in terms of spares requirements. This applies risk-of-failure analysis methods to prediction of spares requirements and maintenance manhours. All predictions were made by the same methods, thus assuring that the data presents the proper range of lative performance for purposes of preferential evaluation and ranking with regard to unscheduled maintenance.

Spare parts cost estimates were introduced into the cost model in terms of initial spares and depot maintenance, measured in terms of equivalent units production subsystem hardware costs. The initial spares are required to re[
any failure present in a returning Tug for the first five flights. The est:
for subsystems assumed at least one of each replaceable item plus several additional parts for those items having a high failure risk and a long flow for depot overhaul. The comparison of costs for the separate subsystems ar(determined. The cost comparison and method of calculation is shown in Section 6.11.4.1 of Volume 6.

Section 5

OPTION 2 SUMMARY

5.1 VEHICLE MANUFACTURING SUMMARY

The vehicle manufacturing plan of the Space Tug (see Figure 5-1) contains the Space Tug manufacturing support of the DDT&E requirements, the Space Tug production manufacturing plan, including peak rate charts, manufacturing flow plans, tooling required to manufacture the Space Tug per the prescribed rate, and the facilities that will be required to accomplish the task. Also included in Volume 8 are the problem areas, special processes required, summary analysis, and manufacturing philosophy engendered into the manufacturing plan.

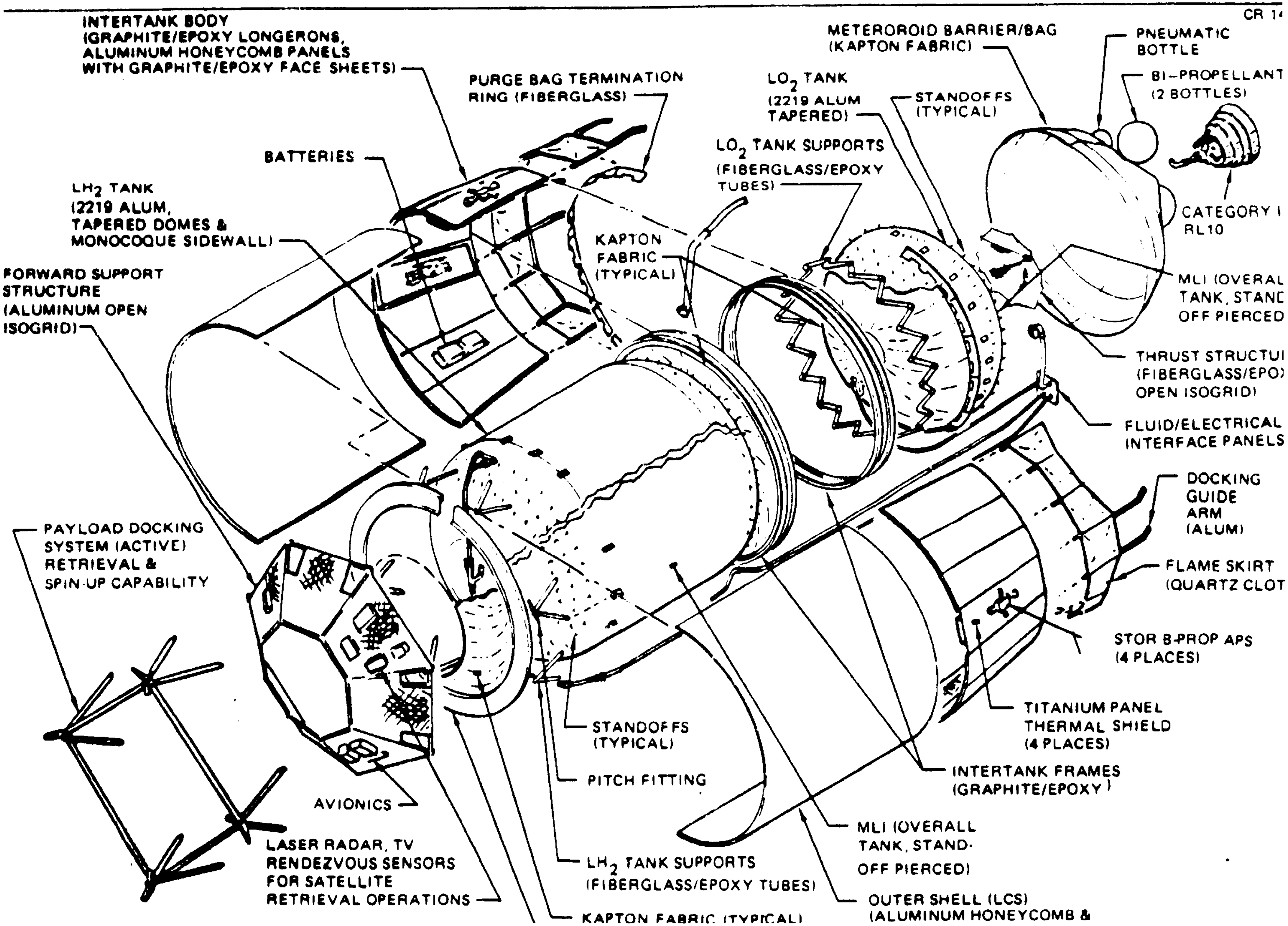
The manufacturing plan flow/time elements used for the manufacture of the Space Tug are based on the following key factors:

- Low production requirements
- Low-cost DDT&E costs
- Low manufacturing costs
- Low early year funding
- Low manufacturing rate requirement
- Test article requirements support
- Utilization of existing capital equipment, GSE, and facilities
- High reliability and reusable requirements of the Space Tug.

The above noted key factors were considered and incorporated into the manufacturing plan with the principal motivating factor being the high reliability and reusability requirement.

5.1.1 Manufacturing Requirements

This section has been divided into two parts to separate the manufacturing requirements for major test articles from those needed for the production of flight articles. No dedicated flight test articles are planned for this program. Schedule requirements for the major test articles are presented in Volume 8, Section 1.2. Wherever practical or feasible from a schedule standpoint, manufactured test components will be fabricated during tool proofing to provide lower program cost, reduce planning effort, provide a greater lead time,


CR 14
INTERTANK BODY (GRAPHITE/EPOXY LONGERONS, ALUMINUM HONEYCOMB PANELS WITH GRAPHITE/EPOXY FACE SHEETS)
PURGE BAG TERMINATION RING (FIBERGLASS)
BATTERIES
LH_2 TANK (2219 ALUM, TAPERED DOMES & MONOCOQUE SIDEWALL)
FORWARD SUPPORT STRUCTURE (ALUMINUM OPEN ISOGRID)
PAYLOAD DOCKING SYSTEM (ACTIVE) RETRIEVAL & SPIN-UP CAPABILITY
AVIONICS
LASER RADAR, TV RENDEZVOUS SENSORS FOR SATELLITE RETRIEVAL OPERATIONS
KAPTON FABRIC (TYPICAL)
LH_2 TANK SUPPORTS (FIBERGLASS/EPOXY TUBES)
PITCH FITTING
STANDOFFS (TYPICAL)
KAPTON FABRIC (TYPICAL)
LO_2 TANK SUPPORTS (FIBERGLASS/EPOXY TUBES)
LO_2 TANK (2219 ALUM TAPERED)
STANDOFFS (TYPICAL)
METEROROID BARRIER/BAG (KAPTON FABRIC)
PNEUMATIC BOTTLE
BI–PROPELLANT (2 BOTTLES)
CATEGORY I RL10
MLI (OVERAL TANK, STAND OFF PIERCED
THRUST STRUCTU (FIBERGLASS/EPO OPEN ISOGRID)
FLUID/ELECTRICAL INTERFACE PANELS
DOCKING GUIDE ARM (ALUM)
FLAME SKIRT (QUARTZ CLOT
STOR B-PROP APS (4 PLACES)
TITANIUM PANEL THERMAL SHIELD (4 PLACES)
INTERTANK FRAMES (GRAPHITE/EPOXY)
MLI (OVERALL TANK, STAND-OFF PIERCED)
OUTER SHELL (LCS) (ALUMINUM HONEYCOMB &

The following test articles will be produced: structural test articles, propulsion test vehicle, integrated avionics test unit, flight control simulation, and flight support equipment.

MDAC does not plan to provide dedicated flight test articles, as the high reliability and reusability stressed in the initial design, and proven in development tests, will ensure flightworthy hardware. A total of 12 flight vehicles will be produced. Manufacture of the flight articles is described elsewhere in this report, together with the production flow for test, integration, insulation and checkout.

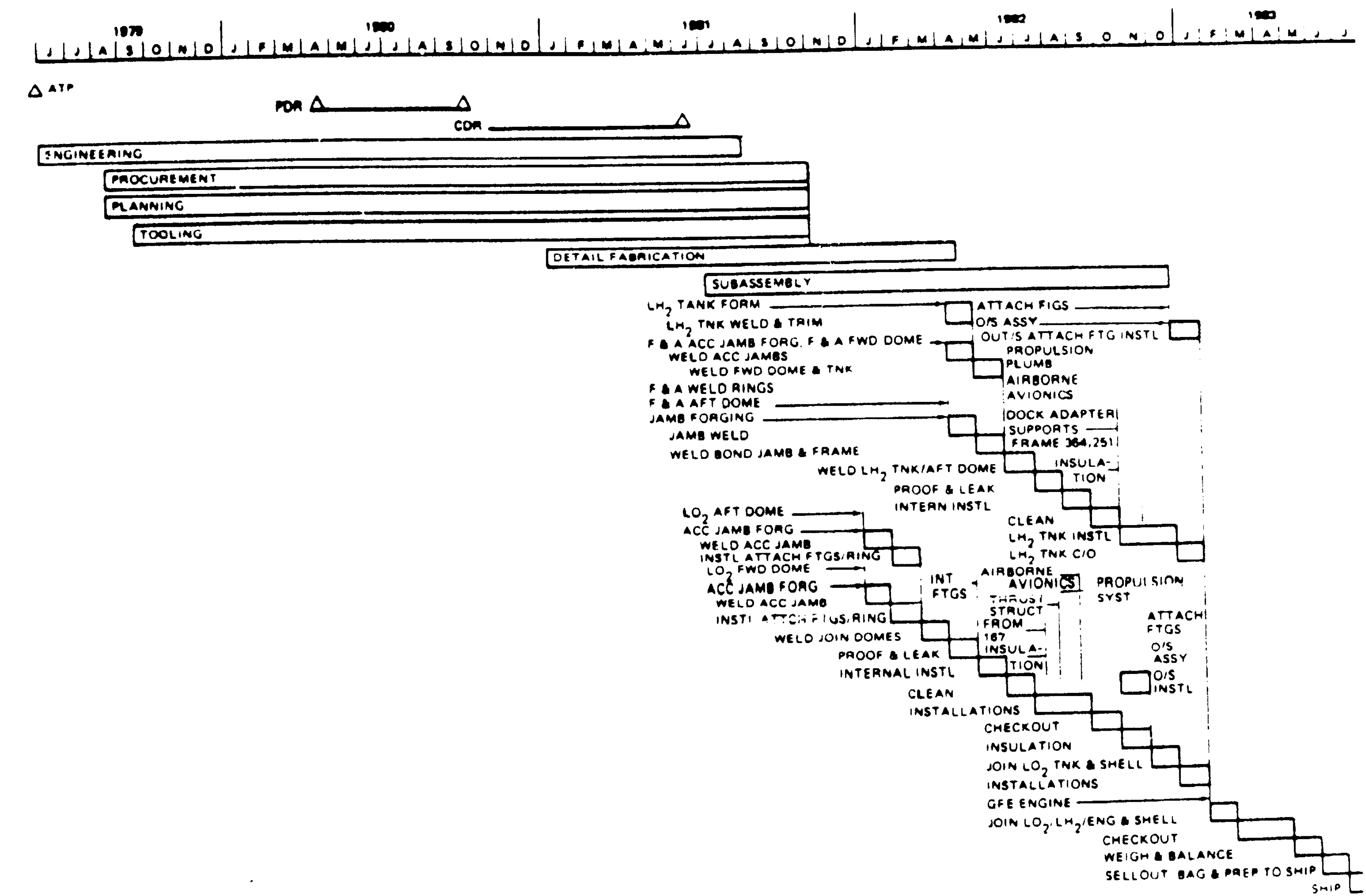
5.1.2 Manufacturing Schedule and Flow

The manufacturing schedule is based on the Production Schedule, shown in Volume 8, Section 1.3, which is the basis also for the manufacturing flow charts, lead time set-back charts, and first tool usage requirements.

The manufacturing flow schedule shown in Figure 5-2 begins with Engineering design effort at ATP, and defines the sequence of activities by Procurement, Planning, Tooling and Manufacturing through detail fabrication, subassembly and assembly, integration and installation, through final checkout and preparation for shipment. Major inspection points such as proof and leak check are also shown in this chart.

The peak rate tree chart presented in Figure 5-3 shows both detailed manufacturing steps and the units in flow at peak production rate.

Additional detailed manufacturing sequence flow charts are contained in the Manufacturing Plan, which is discussed in detail in Volume 8, Section 4.1.3.


1979
1980
1981
1982
1983
J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J
ATP
PDR
CDR
ENGINEERING
PROCUREMENT
PLANNING
TOOLING
DETAIL FABRICATION
SUBASSEMBLY
LH2 TANK FORM
LH2 TNK WELD & TRIM
F & A ACC JAMB FORG, F & A FWD DOME
WELD ACC JAMBS
WELD FWD DOME & TNK
F & A WELD RINGS
F & A AFT DOME
JAMB FORGING
JAMB WELD
WELD BOND JAMB & FRAME
WELD LH2 TNK/AFT DOME
PROOF & LEAK
INTERN INSTL
ATTACH FIGS
O/S ASSY
OUT/S ATTACH FTG INSTL
PROPULSION
PLUMB
AIRBORNE
AVIONICS
DOCK ADAPTER
SUPPORTS
FRAME 364,251
INSULA-
TION
CLEAN
LH2 TNK INSTL
LH2 TNK C/O
LO2 AFT DOME
ACC JAMB FORG
WELD ACC JAMB
INSTL ATTACH FTGS/RING
LO2 FWD DOME
ACC JAMB FORG
WELD ACC JAMB
INSTL ATTACH FTGS/RING
WELD JOIN DOMES
PROOF & LEAK
INTERNAL INSTL
CLEAN
INSTALLATIONS
INT
FTGS
AIRBORNE
AVIONICS
PROPULSION
SYST
THRUST
STRUCT
FROM
167
INSULA-
TION
ATTACH
FTGS
O/S
ASSY
O/S
INSTL
CHECKOUT
INSULATION
JOIN LO2 TNK & SHELL
INSTALLATIONS
GFE ENGINE
JOIN LO2/LH2/ENG & SHELL
CHECKOUT
WEIGH & BALANCE
SELLOUT BAG & PREP TO SHIP
SHIP

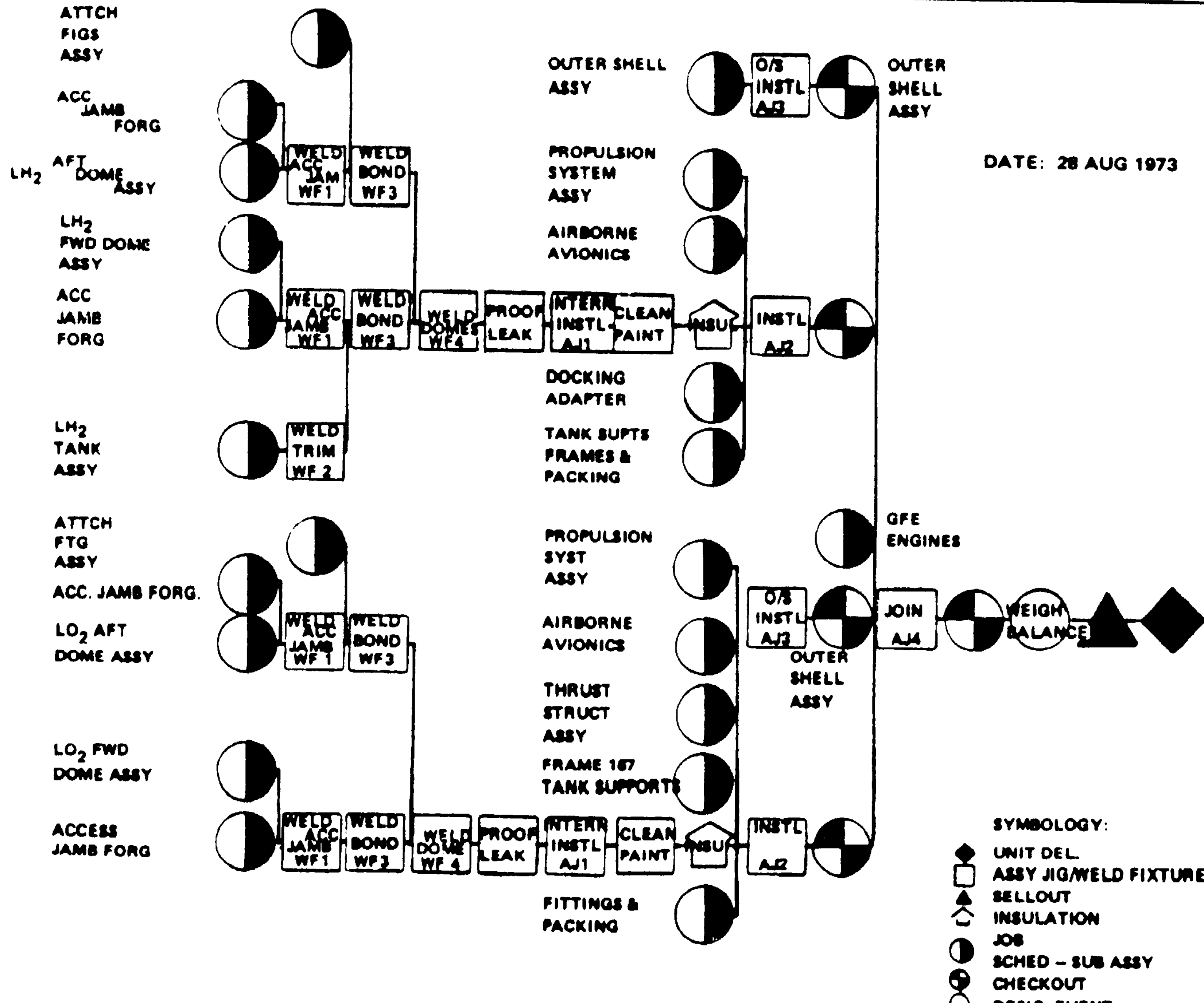


Figure 5-3. Space Tug System Study (Cryogenic) – Peak Rate Tree Chart (Max Rate 4 Per Year) – Option 2

5.1.3 Manufacturing Plan

The manufacturing plan outlined in this section is structured as follows:

- Fabrication and subassembly (structures) plan and flow plan:
- Tank bonding and insulation plan and flow plans
- Final assembly and final joining plan and flow plans
- Propulsion fabrication and subassembly plan and flow plans
- Avionics fabrication and subassembly and installation plans and flow plans.
- Production acceptance test plan.

The fabrication and subassembly requirements for the manufacture of the structural components comprising the space tug are within the state of the art and will not require the development of unique manufacturing processes. Low-cost "soft" tooling-layout templates, router/blocks, drop hammer dies, etc.— will be used extensively where practical. The LH_2 and the LO_2 domes will be subcontracted to a vendor that currently has the capability to manufacture a one-piece dome.

The fusion joining of the LH_2 tanks and the LO_2 tanks will be accomplished using the latest TIG welding techniques. Note: The welding process employe in the manufacture of the Space Tug LH_2 and LO_2 tanks is fully discussed in Volume 8, Section 4.5.

The manufacturing requirements for each of the Space Tug components are outlined in the Space Tug fabrication flow plans. See typical flow plans, Figure 5-4.

The tank bonding and insulation plan for the bonding of the insulation and the Kapton purge bag stand-offs is delineated in the Space Tug fabrication flow plan detailed in Volume 8.

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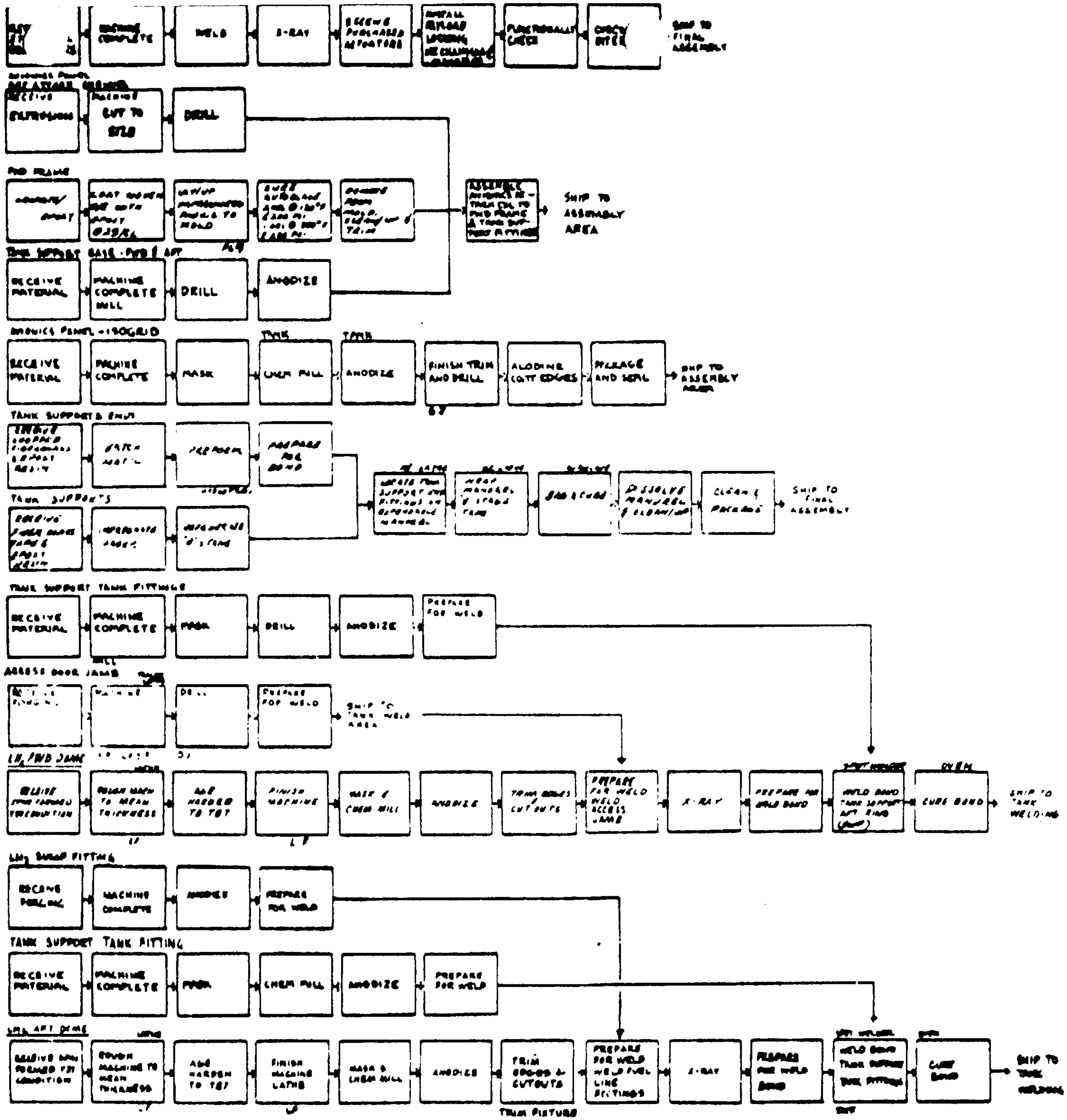


igure 5-4. Space Tug Fabrication Flow Plan – Option 2

flow plan in Figure 5-5. The LO_2 and the LH_2 tanks are built up as modular assemblies in the horizontal mode. The LO_2 and the LH_2 subassembly jigs are then mated per leader pins and index points and the final joining, installations, and checkout are accomplished.

5.2 FACILITIES

The requirements developed by operations analysis in the areas of manufacturi test, integration, C/O launch, recovery, refurbishment, and storage were matched against existing, modified, and new facilities on the basis of availability, compatibility, and cost.

It was determined that facilities are not configuration-sensitive; cost is no a determining factor in selection since existing facilities can be utilized f most requirements.

Tug facilities at ETR will be satisfied by one new building and by modificati and refurbishment of existing buildings, and by use of Orbiter facilities tha can be expanded or adapted to include Tug service.

At WTR, construction of a new payload processing facility together with use o programmed Shuttle facilities expanded to satisfy Tug needs will provide the support required.

Manufacturing facilities will be based on existing MDAC plant and equipment a Huntington Beach, California, modified and augmented by autoclaves-presses, e as required to produce Tug.

Production testing will be done at Huntington Beach. Some vehicle tests will accomplished at NASA facilities at Huntsville and AEDC facilities at Tullahom Only such GSE as is needed for handling, loading, and other Tug-peculiar requirements will be provided at test facilities.

Tabulations of all facility requirements, their cost, location, and lead time are shown in Tables 5-1 and 5-2.

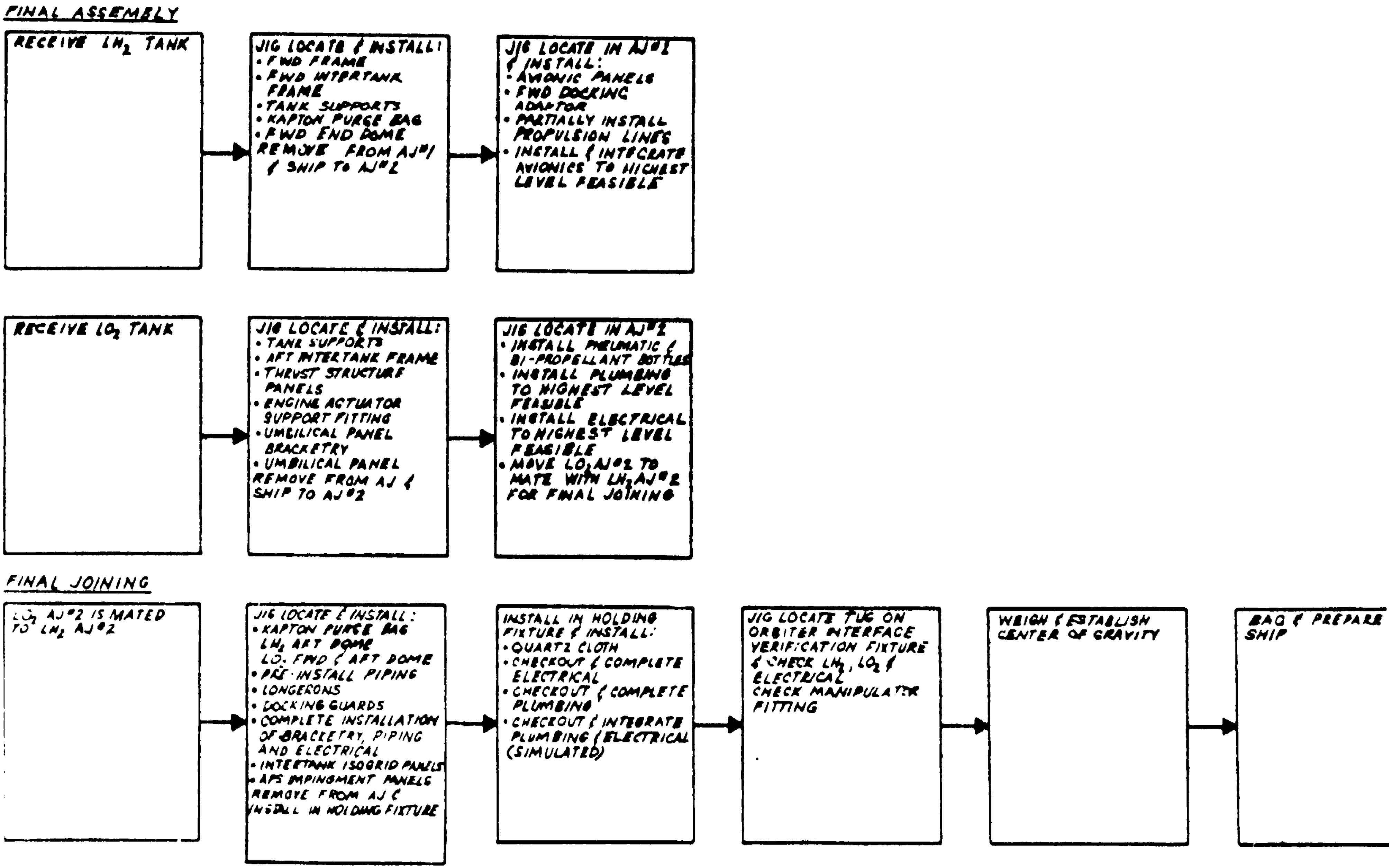


Figure 5-5. Space Tug Final Assembly/Joining Flow Plan – Option 2

Table 5-1

OPERATIONAL FACILITIES SUMMARY

Facility	Origin	KSC	
Tug Processing Facility	Modified KSC Bldg M7-355	$ 500,000	
DOD Payload Processing Facility	New	500,000	
Payload Processing Facility	New		$ 7
Maintenance and CO Facility	Modified Shuttle Facility	10,000	
Maintenance and CO Facility	Modified Shuttle Facility		
Launch Service Structure	Modified Shuttle Facility	350,000	
Launch Service Structure	Modified Shuttle Facility		3
Launch Control Center	Modified Shuttle Facility	10,000	
Launch Control Center	Modified Shuttle Facility		
Safing Facility	Modified Shuttle Facility	-0-	
Safing Facility	Modified Shuttle Facility		
Storable Propellant Facility	Modified Shuttle Facility	-0-	
Storable Propellant Facility	Modified Shuttle Facility		
Vertical Assembly Building	Modified Shuttle Facility	10,000	
Vertical Assembly Building	Modified Shuttle Facility		
		$1,380,000	$1,

Table [illegible]-2

ADDITIONAL MANUFACTURING FACILITIES

Description	Lead Time	ROM Cost Option 1 and 3	ROM Cost Option 2
1. Aging oven 20 x 20 x 8 ft (325°F)	6 months	$ 30,000	
2. Autoclave 16 ft dia x 12 ft long (600°F)	10 months	130,000	
3. Chem-mill facility 2 tanks 20 x 20 x 12 ft	10 months	200,000	
4. Anodize facility 20 x 20 x 10 ft tanks	4 months	200,000	
5. Clean room/10-ton bridge crane 5,000 sq ft (100,000 Class)	8 months	250,000	
6. Acoustic emission test equipment (Pate)		150,000	
7. Acoustic emission test equipment (Pate)		75,000	
			$1,035,000
8. Curing oven 16 x 16 x 8 ft (600°F)	6 months		60,000
T o t a l		$1,035,000	$1,095,000

Test Facilities

	NASA	DOD
1. MDAC Huntington Beach Labs	-0-	-0-
2. NASA Huntsville High Vacuum Facility	-0-	250,000
3. AEDC Tullahoma Mark 4 Chamber	1,250,000	-0-

The acquisition of assurance of reusability of the cryogenic Space Tug thr equipment life, maintainability, and/or refurbishment begins with design a continues through component and vehicle-level testing to mission operation

Design for high reliability and judiciously planned and implemented testin must be used to insure the specified reusability and life of the Space Tug

The most cost-effective program combined the four following philosophies f design, analyses, and test.

A. Select existing hardware which is shown to have survived space f

B. Design new subsystem hardware to survive an economically reasona portion of Tug life.

C. Determine, through reliability analyses, that component reliabil meets Tug requirements and that failures which may occur must be considered random failures.

D. Determine that a component/subassembly/assembly/subsystem cannot removed and replaced through scheduled or unscheduled maintenanc design for survival through Tug environmental criteria beyond expected life.

The majority of the components intended for this configuration have been developed for use in previously produced space vehicles, are standard components qualified for space vehicle applications, or will require little modification to meet Space Tug specifications. For those components requir new or further development or requalification, an economically feasible population will be selected for the appropriate type of testing. Further, level of hardware assembly at which verification of a given item can be ade achieved, i.e., component, subassembly, assembly, etc., will be evaluated. the maximum extent possible, qualification of hardware included in the desi

...ty, long life components and parts, and the component verification approach outlined above should yield an approximate 10 percent reduction of operational maintenance and refurbishment costs. DDT&E costs will be higher due to testing and its associated population requirements to provide reliability and life; however, this cost is nonrecurring and will produce a reduction in recurring costs by lowering the incidence of both scheduled and unscheduled maintenance and refurbishment.

5.3.1 Vehicle Ground Test Summary

Tests to be conducted with the major test articles are summarized in Table 5-3. The testing program is designed to provide the maximum confidence possible, consistent with minimum DDT&E funding of this option. Test descriptions and estimates are provided in Volume 8.

Flight test data will be acquired in conjunction with normal mission performance. Flight test objectives are aimed at verifying that the Space Tug can perform assigned missions within the specified mission envelope of performance and time requirements.

5.3.2 Flight Test Summary

The first produced Tug will be equipped with special flight test instrumentation and equipment in support of the following objectives:

- A. Propellant settling.
- B. Propellant utilization.
- C. Propellant feedline and engine thermal conditioning.
- D. Engine low-pressure ignition.
- E. Zero-g heat transfer.
- F. Avionics cold plate temperature stabilization.
- G. Vibration levels of selected critical installations.

Pressure burst tanks (Development)	X	X	X
Pressure cycle/proof tanks and static loading of remainder of structures subsystems (Qualification)	X	X	X
Maintenance ($\overline{M}$) procedures verification (DT&E, IOT&E) - Development fixture	X	X	X
Maintainability ($\underline{M}$) evaluation - Development fixture	X	X	X
Propulsion test vehicle - cold flow (Cat I RL10 engine)			
Propulsion test vehicle - static firing (Other than Cat I RL10)	X	X	X
Maintainability ($\underline{M}$) evaluation - PTV	X	X	X
Integrated avionics test unit (IATU) (DT&E, IOT&E)	X	X	X
Maintainability ($\underline{M}$) evaluation - IATU	X	X	X
Flight control simulation (Deployment only)			
Flight control simulation (Deployment and retrieval)	X	X	X
Transportation and handling procedures verification, flight test article (DT&E, IOT&E)	X	X	X
Thermal	X	X	X
EMC - Flight test article, manufacturing	X	X	X
EMC - First delivered Tug, ETR	X	X	X
EMC - First delivered Tug, WTR	X	X	X
$\overline{M}$ - Flight test article, ETR	X	X	X
$\underline{M}$ - Flight test article, WTR	X	X	X
Flight support equipment with an IVU	X	X	X
Flight support equipment with an IVU and the Shuttle Orbiter (Egress-ingress)	X	X	X
Flight test operation - Egress-ingress maneuver verification using the IVU	X	X	X
Flight test operation - Two flights with operational missions	X		X
Flight test operations - Two flights, dedicated		X	
Flight test operations - One flight with operational mission			
Flight test operations - One flight, dedicated			

turnaround cycle. This Tug will then continue normal operations within the fleet.

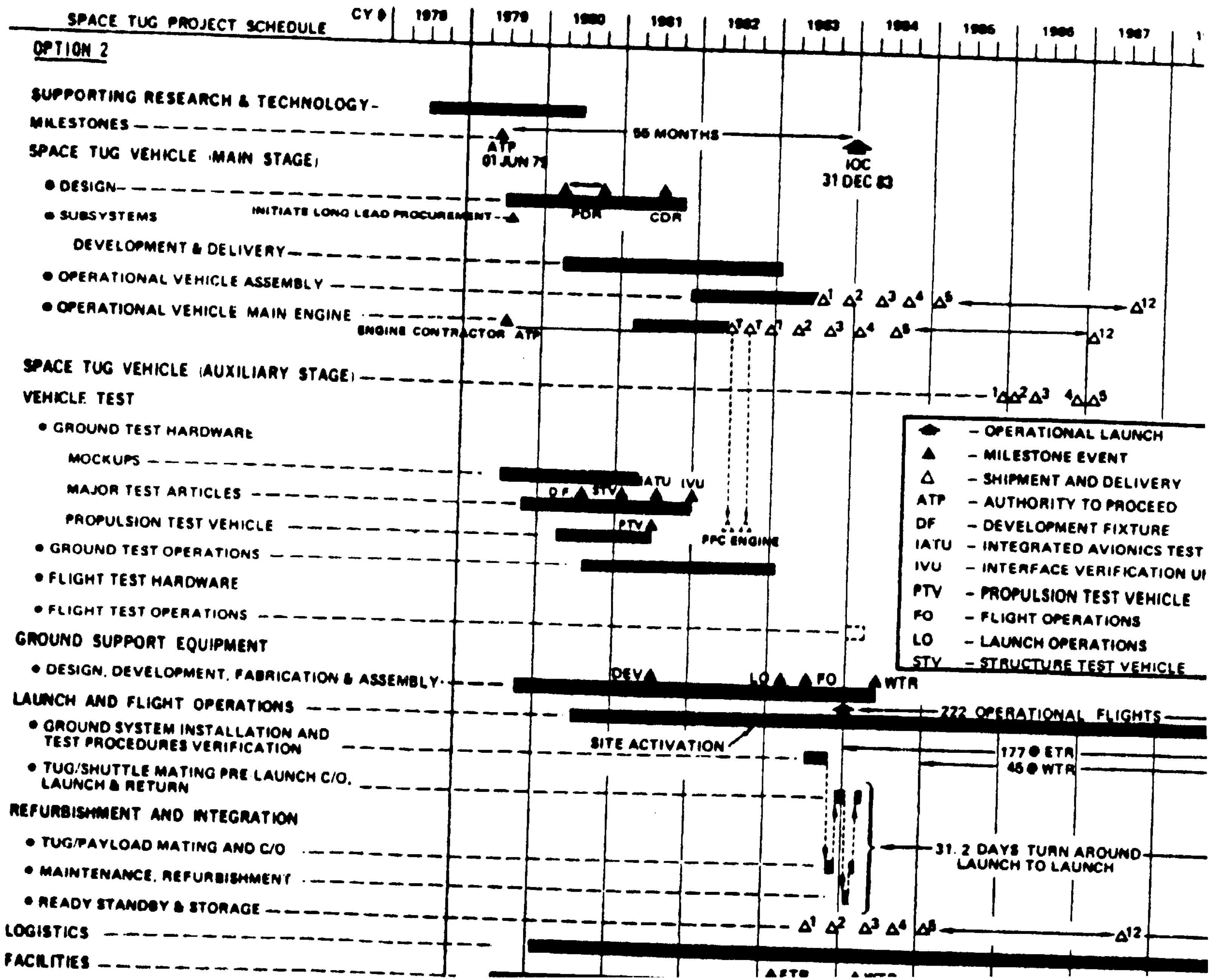
5.4 SCHEDULE SUMMARY (NASA ACQUISITION)

The schedule (Figure 5-6) for Space Tug Option 2 is based on a Phase C/D design development and operations authority to proceed (ATP) in June 1979. Design development, test, and evaluation requires 55 months and will be completed at the first Space Tug operational launch on December 31, 1983. Seven years of flight operations are assumed, beginning with the first operational launch and ending in 1990.

Completion of the Space Tug preliminary design review is scheduled for October 1980 to establish firm vehicle configurations. A critical design review will be completed in August 1981 to assure that design requirements have been met.

The ground test program will use subsystem models for concept and design development and design qualification. Qualification of subsystems will be completed in November 1982, 41 months after ATP. System-level test articles will be used in the ground test program for subsystem integration and interface verification activities. Two Space Tug vehicles are required at IOC to support the initial requirement of 20 flights in the first year of operations. A total of 12 vehicles are produced and delivered over a period of four years. Vehicles are stored at the launch facility and used as required to support launch and refurbishment operations.

Operational flights start at IOC, December 31, 1983 and end with the 222nd flight in 1990; 177 flights are launched from ETR and 45 flights are launched from WTR. No dedicated flight test operations are required.


SPACE TUG PROJECT SCHEDULE
OPTION 2
CY
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
SUPPORTING RESEARCH & TECHNOLOGY
MILESTONES
ATP
01 JUN 79
56 MONTHS
IOC
31 DEC 83
SPACE TUG VEHICLE (MAIN STAGE)
• DESIGN
PDR
CDR
• SUBSYSTEMS
INITIATE LONG LEAD PROCUREMENT
DEVELOPMENT & DELIVERY
• OPERATIONAL VEHICLE ASSEMBLY
• OPERATIONAL VEHICLE MAIN ENGINE
ENGINE CONTRACTOR ATP
SPACE TUG VEHICLE (AUXILIARY STAGE)
VEHICLE TEST
• GROUND TEST HARDWARE
MOCKUPS
MAJOR TEST ARTICLES
DF
STV
IATU
IVU
PROPULSION TEST VEHICLE
PTV
PFC ENGINE
• GROUND TEST OPERATIONS
• FLIGHT TEST HARDWARE
• FLIGHT TEST OPERATIONS
GROUND SUPPORT EQUIPMENT
• DESIGN, DEVELOPMENT, FABRICATION & ASSEMBLY
DEV
LO
FO
WTR
LAUNCH AND FLIGHT OPERATIONS
222 OPERATIONAL FLIGHTS
• GROUND SYSTEM INSTALLATION AND TEST PROCEDURES VERIFICATION
SITE ACTIVATION
177 ● ETR
45 ● WTR
• TUG/SHUTTLE MATING PRE LAUNCH C/O, LAUNCH & RETURN
REFURBISHMENT AND INTEGRATION
• TUG/PAYLOAD MATING AND C/O
31.2 DAYS TURN AROUND LAUNCH TO LAUNCH
• MAINTENANCE, REFURBISHMENT
• READY STANDBY & STORAGE
LOGISTICS
FACILITIES
– OPERATIONAL LAUNCH
– MILESTONE EVENT
– SHIPMENT AND DELIVERY
ATP – AUTHORITY TO PROCEED
DF – DEVELOPMENT FIXTURE
IATU – INTEGRATED AVIONICS TEST
IVU – INTERFACE VERIFICATION U
PTV – PROPULSION TEST VEHICLE
FO – FLIGHT OPERATIONS
LO – LAUNCH OPERATIONS
STV – STRUCTURE TEST VEHICLE

B. Cost Summary

C. Cost Per Flight Data Sheets.

See Volume 8, Book 2 for detailed cost information.

The summary cost tabulation is derived from the LEADER II cost model printout. The cost summary presents a technical summary, a schedule summary, an annual funding summary, and a cumulative funding summary. The cost per flight data sheets have been prepared in accordance with NASA Direction (Letter PD-TUG-P (015-74, dated 3 August 1973, from J. A. Stucker, Manager, Program Planning and Control) to A. G. Orillion (COR, PD-TUG-C).

Table 5-4

PROGRAM OPTION NO. 2

SUMMARY COST TABULATION

1973 DOLLARS IN MILLIONS

TOTAL PROGRAM COSTS	
DDT&E	$298.77
PRODUCTION	214.29
OPERATIONS	169.44
	$682.50

UNIT COSTS	
VEHCILE MAIN STAGE	
FIRST PRODUCTION UNIT - HARDWARE	
AVERAGE UNIT (INCLUDING SUPPORT)	
VEHICLE AUXILIARY STAGE	
AVERAGE UNIT (INCLUDING START UP)	
AVERAGE COST PER FLIGHT	
MODE 1 - NASA	
MODE 1 - DOD	
MODE 2 - NASA	
MODE 2 - DOD	Not
MODE 3 - NASA	
MODE 3 - DOD	Not

TECHNICAL CHARACTERISTICS – OPTION NO. 2

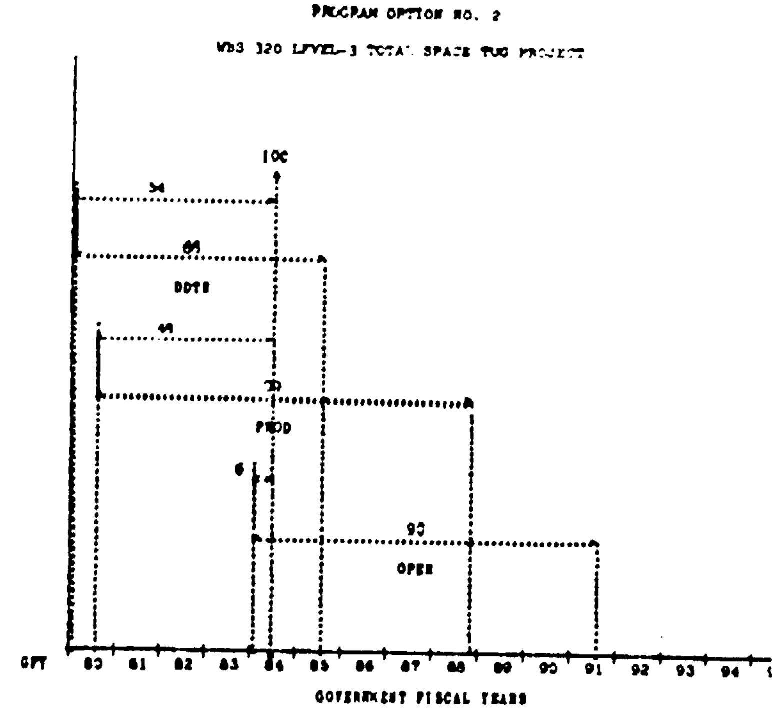
WBS 320 TOTAL SPACE TUG PROJECT

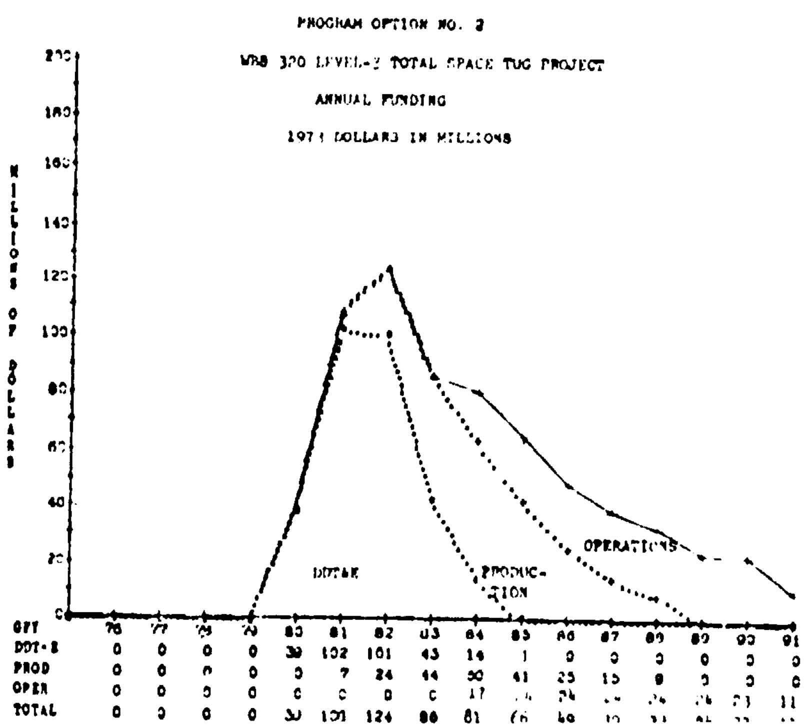
MAJOR HARDWARE

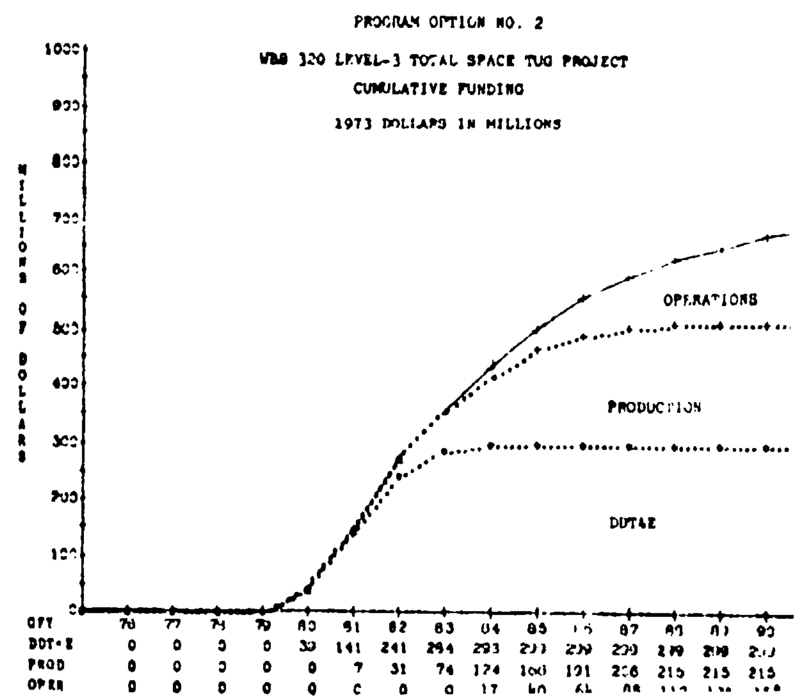
SPACE TUG VEHICLE MAIN STAGE	12 VEHICLES
SPACE TUG VEHICLE AUXILIARY STAGE	5 STAGES

OTHER SYSTEM ELEMENTS

PROJECT MANAGEMENT	
SYSTEMS ENGINEERING & INTEGRATION	
LOGISTICS	TRANSP., TRAINING, SIMULATION
FACILITIES	FACTORY, TEST, ETR, WTR
GROUND SUPPORT EQUIPMENT	FACTORY, ETR, WTR
VEHICLE TEST	FTV, MAJOR TEST ARTICLES
LAUNCH OPERATIONS – WTR	46 LAUNCHES
LAUNCH OPERATIONS – ETR	179 LAUNCHES
FLIGHT OPERATIONS – NASA	117 FLIGHTS
FLIGHT OPERATIONS – DOD	105 FLIGHTS
REFURBISHMENT & MAINTENANCE – WTR	46 REFURBS.
REFURBISHMENT & MAINTENANCE – ETR	179 REFURBS.







Tug/Shuttle mating and checkout	$ 17,007	
Tug/Payload mating and checkout	27,094	
Prelaunch checkout	20,691	
Countdown	33,069	
Propellant and gases	6,401	
Post flight safing	27,269	
Site services and support	62,283	
MAINTENANCE AND REFURBISHMENT		$ 215,322
Scheduled maintenance and refurbishment	$ 34,319	
Unscheduled maintenance and refurbishment	10,359	
Tug engine maintenance and refurbishment	12,778	
Tug vehicle spares	35,272	
Tug engine spares	7,341	
Post maintenance checkout	2,652	
Refurbishment requirements planning	7,835	
Depot maintenance	104,766	
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 409.136
FLIGHT OPERATIONS		$ 213,000
Mission planning	$ 54,000	
Flight control	79,000	
Flight evaluation	57,000	
Flight software	23,000	
OPERATIONS SUPPORT		$ 128,385
Airborne software update	$ 9,937	
GSE maintenance	15,667	
Sustaining engineering	31,915	
Program management	29,319	
Transportation and handling	1,388	
Inventory control and warehousing	20,904	
Facilities maintenance	3,670	
GSE software update	15,585	
EXPENDABLE VEHICLE MAIN STAGE		$ 0
EXPENDABLE VEHICLE AUXILIARY STAGE		$ 0
TOTAL AVERAGE PER FLIGHT COST		$ 750,[illegible]

Tug/Shuttle mating and checkout	$ ________	NOT REQUIRED
Tug/Payload mating and checkout	________	
relaunch checkout	________	
Countdown	________	
Propellant and gases	________	
Post flight safing	________	
Site services and support	________	
AINTENANCE AND REFURBISHMENT		$ ________
Scheduled maintenance and refurbishment	$ ________	
Unscheduled maintenance and refurbishment	________	
Tug engine maintenance and refurbishment	________	
Tug vehicle spares	________	
Tug engine spares	________	
Post maintenance checkout	________	
Refurbishment requirements planning	________	
Depot maintenance	________	
OTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ ________
L HT OPERATIONS		$ ________
Mission planning	$ ________	
Flight control	________	
Flight evaluation	________	
Flight software	________	
PERATIONS SUPPORT		$ ________
Airborne software update	$ ________	
GSE maintenance	________	
Sustaining engineering	________	
Program management	________	
Transportation and handling	________	
Inventory control and warehousing	________	
Facilities maintenance	________	
GSE software update	________	
G DABLE VEHICLE MAIN STAGE		$ ________
PENDABLE VEHICLE AUXILIARY STAGE		$ ________
		________

Tug/Shuttle mating and checkout	$	NOT REQUIRED
Tug/Payload mating and checkout		
Prelaunch checkout		
Countdown		
Propellant and gases		
Post flight safing		
Site services and support		
MAINTENANCE AND REFURBISHMENT		$
Scheduled maintenance and refurbishment	$	
Unscheduled maintenance and refurbishment		
Tug engine maintenance and refurbishment		
Tug vehicle spares		
Tug engine spares		
Post maintenance checkout		
Refurbishment requirements planning		
Depot maintenance		
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$
FLIGHT OPERATIONS		$
Mission planning	$	
Flight control		
Flight evaluation		
Flight software		
OPERATIONS SUPPORT		$
Airborne software update	$	
GSE maintenance		
Sustaining engineering		
Program management		
Transportation and handling		
Inventory control and warehousing		
Facilities maintenance		
GSE software update		
XPENDABLE VEHICLE MAIN STAGE		$
EXPENDABLE VEHICLE AUXILIARY STAGE		$
TOTAL AVERAGE PER FLIGHT COST		

AUNCH OPERATIONS		$ 205,898
Tug/Shuttle mating and checkout	$ 18,296	
g/Payload mating and checkout	29,533	
Prelaunch checkout	22,033	
Countdown	34,836	
Propellant and gases	6,478	
Post flight safing	28,314	
Site services and support	66,408	
INTENANCE AND REFURBISHMENT		$ 221,107
Scheduled maintenance and refurbishment	$ 36,868	
Unscheduled maintenance and refurbishment	11,023	
Tug engine maintenance and refurbishment	12,932	
Tug vehicle spares	35,696	
Tug engine spares	7,429	
Post maintenance checkout	2,809	
Refurbishment requirements planning	8,327	
Depot maintenance	106,023	
[illegible] GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 427,005
IGHT OPERATIONS		$ 204,000
Mission planning	$ 51,000	
Flight control	78,000	
Flight evaluation	53,000	
Flight software	22,000	
RATIONS SUPPORT		$ 128,715
Airborne software update	$ 10,056	
GSE maintenance	15,855	
Sustaining engineering	32,298	
Program management	29,671	
Transportation and handling	1,404	
Inventory control and warehousing	21,155	
Facilities maintenance	3,715	
[illegible] software update	14,561	
ENDABLE VEHICLE MAIN STAGE		$ 0
ENDABLE VEHICLE AUXILIARY STAGE		$ 0

MODE 2 Expended Tug (continued) PROGRAM OPTION

LAUNCH OPERATIONS		$ 205,898
Tug/Shuttle mating and checkout	$ 18,296	
Tug/Payload mating and checkout	29,533	
Prelaunch checkout	22,033	
Countdown	34,836	
Propellant and gases	6,478	
Post flight safing	28,314	
Site services and support	66,408	
MAINTENANCE AND REFURBISHMENT		$
Scheduled maintenance and refurbishment	$	
Unscheduled maintenance and refurbishment		
Tug engine maintenance and refurbishment		
Tug vehicle spares		
Tug engine spares		
Post maintenance checkout		
Refurbishment requirements planning		
Depot maintenance		
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 205,898
FLIGHT OPERATIONS		$ 204,000
Mission planning	$ 51,000	
Flight control	78,000	
Flight evaluation	53,000	
Flight software	22,000	
OPERATIONS SUPPORT		$ 128,715
Airborne software update	$ 10,056	
GSE maintenance	15,855	
Sustaining engineering	32,298	
Program management	29,671	
Transportation and handling	1,404	
Inventory control and warehousing	21,155	
Facilities maintenance	3,715	
GSE software update	14,561	
EXPENDABLE VEHICLE MAIN STAGE		$ 16,410,000
EXPENDABLE VEHICLE AUXILIARY STAGE		$ 0

: 3 Expended Kick Stage (Continued) PROGRAM OPTION 2

ICH OPERATIONS		$ 205,898
Tug/Shuttle mating and checkout	$ 18,296	
'ug/Payload mating and checkout	29,533	
'relaunch checkout	22,033	
:ountdown	34,836	
'ropellant and gases	6,478	
'ost flight safing	28,314	
;ite services and support	66,408	
ITENANCE AND REFURBISHMENT		$ 221,107
;cheduled maintenance and refurbishment	$ 36,868	
Inscheduled maintenance and refurbishment	11,023	
'ug engine maintenance and refurbishment	12,932	
'ug vehicle spares	35,696	
'ug engine spares	7,429	
'ost maintenance checkout	2,809	
le rbishment requirements planning	8,327	
Depot maintenance	106,023	
L GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 427,005
;HT OPERATIONS		$ 204,000
lission planning	$ 51,000	
'light control	78,000	
'light evaluation	53,000	
'light software	22,000	
RATIONS SUPPORT		$ 128,715
lirborne software update	$ 10,056	
GSE maintenance	15,855	
Sustaining engineering	32,298	
'rogram management	29,671	
Transportation and handling	1,404	
Inventory control and warehousing	21,155	
F lities maintenance	3,715	
GSE software update	14,561	
ENDABLE VEHICLE MAIN STAGE		$ 0
ENDABLE VEHICLE AUXILIARY STAGE		$ 3,470,000

5.6 SCHEDULE SUMMARY (DOD ACQUISITION)

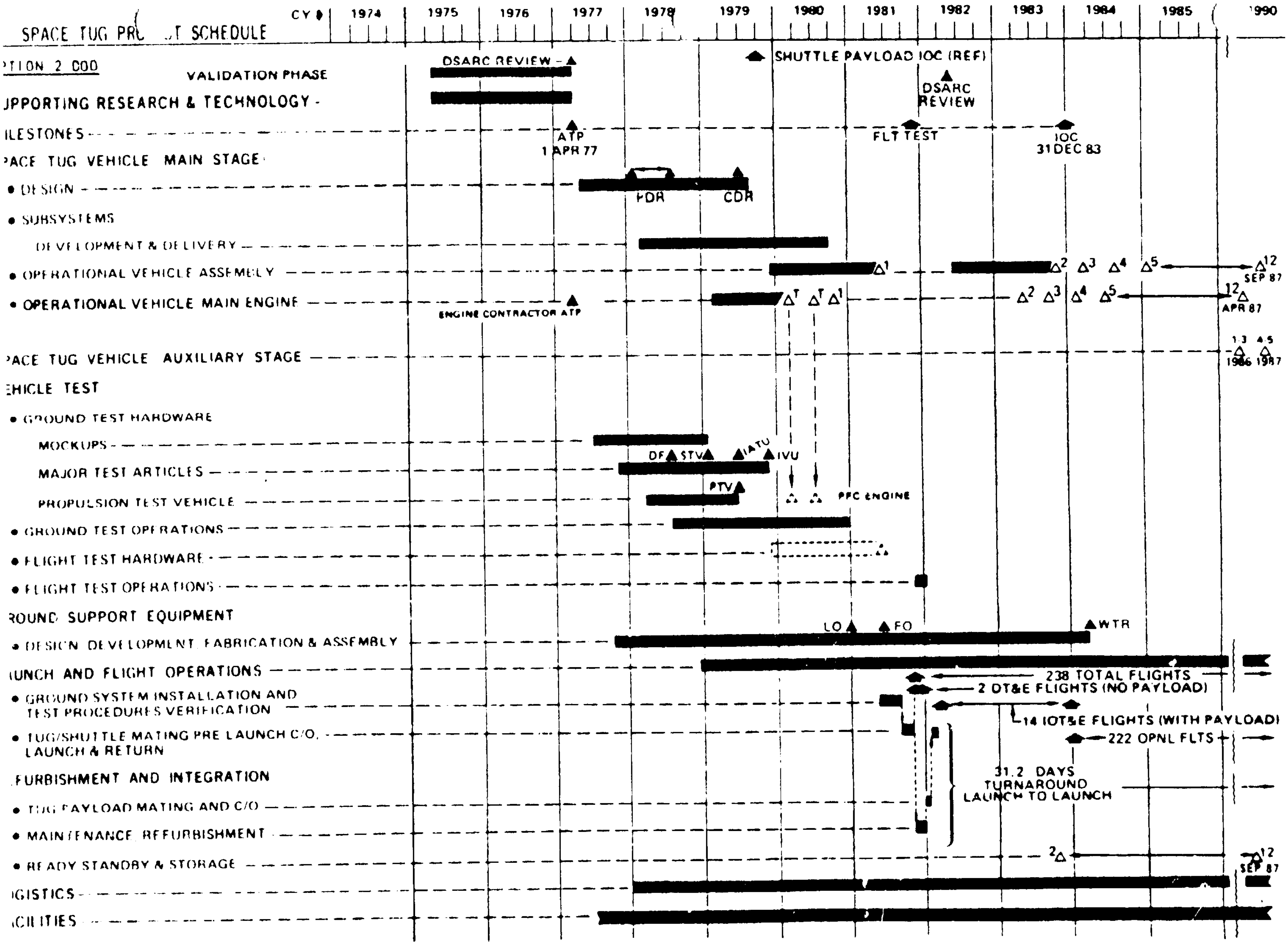
The schedule (Figure 5-7) for Space Tug Option 2 DOD is based on Phase C/D design, development, and operations authority to proceed (ATP) in April 1977. Design, development, test, and evaluation requires 55 months and is completed following dedicated flight tests; 8.6 years of flight operations are assumed beginning with the first payload launch in March 1982 and ending in 1990.

Space Tug preliminary design review is scheduled for 15 months after ATP to establish firm phased vehicle configurations. Critical design review will be completed at 27 months after ATP to ensure that design requirements have been met.

The ground test program will use subsystem models for concept and design develo ment and design qualification. Qualifications of subsystems will be complete i July 1980, 39 months after ATP. System-level test articles will be used in the ground test program for subsystem integration and interface verification activi ties. Two Space Tug vehicles are required at IOC to support the initial requir ments of 20 flights in the first year of operations. A total of 12 vehicles are produced and delivered over a period of four years. Vehicles are stored at the launch facility and used as required to support launch and refurbishment operat

All Space Tug vehicles are produced in the same factory manufacturing and testi facilities and subjected to the same development, qualification, and production acceptance testing. The first unit is used as the full-scale development phase flight test vehicle and, subsequently, to fly initial payload/IOT&E flights unt the production vehicles become available. The first vehicle will be flown twice to validate operation, refurbishment, and maintenance. The vehicle is the made ready to start payload flights following DSARC review and production go-ah

Payload flights begin following DSARC III review and production go-ahead in March 1981. Fourteen payload/IOT&E flights are completed over a 1.8-year perio using flight vehicle No. 1. The first operational flights begin on 31 December 1983 using production vehicles; 222 operational flights take place over a seven-year period, ending in December 1990.



…e 5-7. Schedule Summary – DOD Acquisition

5.7 COST SUMMARY (DOD ACQUISITION)

Summary cost data for this program option, in accordance with the DOD acquisition approach (AFSCP 800-3), are presented in Tables 5-7 through 5-10:

A. Summary Cost Tabulations

B. Annual Funding

C. Cost Per Flight Data Sheets.

See Volume 8, Book 2 for detailed cost information.

The summary cost tabulation is derived from the LEADER II cost model printout provided in Volume 8, Book 2, Section 12. The annual funding chart (Table 5- and Figure 5-8) displays fiscal-year funding requirements for the program by program phase and by agency (DOD/NASA). The cost per flight data sheets have been prepared in accordance with NASA direction (Letter PD-TUG-P(015-74), dat August 3, 1973, from J. A. Stucker, Manager, Program planning and Control to A. G. Orillion (COR, PD-TUG-C). No cost per flight data sheets have been provided for flight modes 2 and 3 since the DOD does not require flights in these modes.

Table 5-7

PROGRAM OPTION NO. 2 - DOD

COST SUMMARY TABULATION

1973 DOLLARS IN MILLIONS

	VALIDATION PHASE	FULL SCALE DEVELOPMENT PHASE	PRODUCTION PHASE	OPERATIONS PHASE	TOTAL COST
)D	43.51	314.66	171.14	76.98	606.29
\SA	-0-	18.76	13.59	59.35	91.70
)TAL	43.51	333.42	184.73	136.33	697.99

Table 5-8

PROGRAM OPTION NO. 2 - DOD

UNIT COST TABULATION

1973 DOLLARS IN MILLIONS

VEHICLE MAIN STAGE	
FIRST PRODUCTION UNIT -- HARDWARE	$16.62
AVERAGE UNIT (INCLUDING SUPPORT)	14.26
VEHICLE AUXILIARY STAGE	
AVERAGE UNIT (INCLUDING SUPPORT)	2.72
AVERAGE COST PER FLIGHT	
MODE 1 -- NASA	0.74
MODE 1 -- DOD	0.73
MODE 2 -- NASA	14.80
MODE 2 -- DOD	NONE REQUIRED
MODE 3 -- NASA	3.46
MODE 3 -- DOD	NONE REQUIRED

PROGRAM OPTION NO. - DOD

WBS 320 LEVEL - 3 TOTAL SPACE TUG PROJECT

ANNUAL FUNDING - TABULAR

1973 DOLLARS IN MILLIONS

75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
5.4	21.8	16.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43.5
0	0	2.0	41.0	92.2	89.7	41.7	24.9	16.1	7.0	0	0	0	0	0	0	0	314.6
0	0	0	0	0	0	.1	56.6	12.4	66.2	9.6	9.6	9.7	2.1	0	0	0	171.3
0	0	0	0	0	0	0	0	0	6.0	11.5	11.5	11.5	11.5	11.5	11.5	2.0	77.0
5.4	21.8	18.3	41.0	92.2	89.7	41.8	81.5	28.5	79.2	21.1	21.1	21.2	13.6	11.5	11.5	2.0	606.4
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	.2	2.5	5.4	5.4	2.5	1.5	.9	.4	0	0	0	0	0	0	0	18.8
0	0	0	0	0	0	0	4.5	1.0	5.2	.8	.8	.8	.5	0	0	0	13.6
0	0	0	0	0	0	0	0	0	6.2	8.5	8.5	8.5	8.5	8.5	8.5	2.2	59.4
0	0	.2	2.5	5.4	5.4	2.5	6.0	1.9	11.8	9.3	9.3	9.3	9.0	8.5	8.5	2.2	91.8
5.4	21.8	18.5	43.5	97.6	95.1	44.3	87.5	30.4	91.0	30.4	30.4	30.5	22.6	20.0	20.0	4.2	698.2

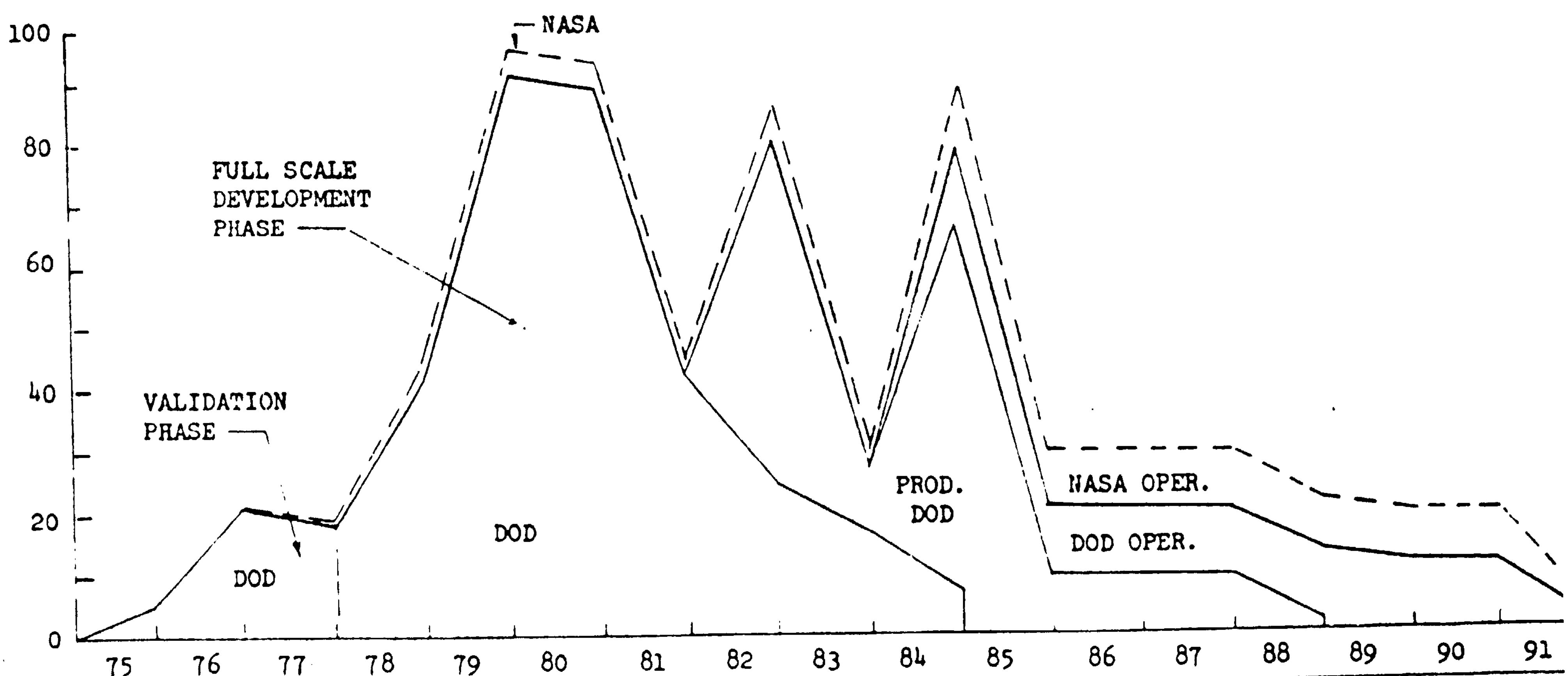
Figure 5-8 PROGRAM OPTION No. 2 - DOD

WBS 320 LEVEL 3 — TOTAL SPACE TUG PROJECT

ANNUAL FUNDING

1973 DOLLARS IN MILLIONS

REPLACEMENT PAGE
Vol. 2,
Page 5-3?



	5.4	21.8	18.3	41.0	92.2	89.7	41.8	81.5	28.5	79.2	21.1	21.1	21.2	13.6	11.5	11.5	2.0
A	0	0	0.2	2.5	5.4	5.4	2.5	6.0	1.9	11.8	9.3	9.3	9.3	9.0	8.5	8.5	2.2

Reusable Basic Stage

PROGRAM OPTION 2 DOD.

		$ 191,104
OPERATIONS		
Shuttle mating and checkout	$ 17,007	
Payload mating and checkout	24384	
aunch checkout	20,691	
tdown	33,069	
ellant and gases	6,401	
flight safing	27,269	
services and support	62,283	
		$ 199,328
ANCE AND REFURBISHMENT		
duled maintenance and refurbishment	$ 30,887	
heduled maintenance and refurbishment	9323	
engine maintenance and refurbishment	12,778	
vehicle spares	35,272	
engine spares	7,341	
maintenance checkout	2,386	
shment requirements planning	7,052	
ot maintenance	94,289	
GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 390,432
		$ 213,000
OPERATIONS		
sion planning	$ 54,000	
ght control	79,000	
ght evaluation	57,000	
ght software	23,000	
		$ 128,385
IONS SUPPORT		
borne software update	$ 9,937	
maintenance	15,667	
taining engineering	31,915	
gram management	29,319	
nsportation and handling	1,388	
entory control and warehousing	20,904	
ilities maintenance	3,670	
software update	15,585	
		$ 0
ABLE VEHICLE MAIN STAGE		
		$ 0
ABLE VEHICLE AUXILIARY STAGE		

AUNCH OPERATIONS		$ 202,945
V/Shuttle mating and checkout	$ 18,296	
Tug/Payload mating and checkout	26,580	
Prelaunch checkout	22,033	
Countdown	34,836	
Propellant and gases	6,478	
Post flight safing	28,314	
Site services and support	66,408	
AINTENANCE AND REFURBISHMENT		$ 204,602
Scheduled maintenance and refurbishment	$ 33,181	
Unscheduled maintenance and refurbishment	9,921	
Tug engine maintenance and refurbishment	12,932	
Tug vehicle spares	35,696	
Tug engine spares	7,429	
Post maintenance checkout	2,528	
Refurbishment requirements planning	7,494	
pot maintenance	95,421	
OTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 407,547
LIGHT OPERATIONS		$ 204,000
Mission planning	$ 51,000	
Flight control	78,000	
Flight evaluation	53,000	
Flight software	22,000	
PERATIONS SUPPORT		$ 128,715
Airborne software update	$ 10,056	
GSE maintenance	15,855	
Sustaining engineering	32,298	
Program management	29,671	
Transportation and handling	1,404	
Inventory control and warehousing	21,155	
acilities maintenance	3,715	
GSE software update	14,561	
EXPENDABLE VEHICLE MAIN STAGE		$ 0
EXPENDABLE VEHICLE AUXILIARY STAGE		$ 0

· EXPENDED TUG (Continued) PROGRAM OPTION 2

		$ 202,945
OPERATIONS		
Shuttle mating and checkout	$ 18,296	
Payload mating and checkout	26,580	
aunch checkout	22,033	
tdown	34,836	
ellant and gases	6,478	
flight safing	28,310	
services and support	66,408	
ANCE AND REFURBISHMENT		$ 0
duled maintenance and refurbishment	$	
heduled maintenance and refurbishment		
engine maintenance and refurbishment		
vehicle spares		
engine spares		
maintenance checkout		
a shment requirements planning		
t maintenance		
ROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 202,945
		$ 204,000
OPERATIONS		
ion planning	$ 51,000	
ght control	78,000	
ght evaluation	53,000	
ght software	22,000	
IONS SUPPORT		$ 128,715
borne software update	$ 10,056	
maintenance	15,855	
taining engineering	32,298	
gram management	29,671	
nsportation and handling	1,404	
e ry control and warehousing	21,155	
ilities maintenance	3,715	
software update	14,561	
		$ 14,260,000
ABLE VEHICLE MAIN STAGE		$ 0

CH OPERATIONS		$ 202,945
y Shuttle mating and checkout	$ 18,296	
ug/Payload mating and checkout	26,580	
relaunch checkout	22,033	
ountdown	34,836	
ropellant and gases	6,478	
ost flight safing	28,314	
ite services and support	66,408	
TENANCE AND REFURBISHMENT		$ 204,602
cheduled maintenance and refurbishment	$ 33,181	
nscheduled maintenance and refurbishment	9,921	
ug engine maintenance and refurbishment	12,932	
ug vehicle spares	35,696	
ug engine spares	2,429	
ost maintenance checkout	2,528	
r urbishment requirements planning	2,490	
epot maintenance	95,421	
L GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 407,547
HT OPERATIONS		$ 204 000
Mission planning	$ 51,000	
Flight control	78,000	
Flight evaluation	53,000	
Flight software	22,000	
RATIONS SUPPORT		$ 128,715
Airborne software update	$ 10,052	
GSE maintenance	15,855	
Sustaining engineering	32,278	
Program management	29,671	
Transportation and handling	1,400	
I entory control and warehousing	21,155	
Facilities maintenance	3,715	
GSE software update	14,56	
ENDABLE VEHICLE MAIN STAGE		$ Ø
		$ 2,720,000

5.8 PROGRAM MANAGEMENT FOR THE SPACE TUG PROJECT

[ ]'s management approach on the Space Tug project is to apply the tools and techniques most appropriate to ensure project control at an acceptable cost level. Our approach includes reaffirming the Government management requirements so that we can be appropriately responsive to their needs. MDAC's management tools and techniques have evolved during extensive development and use with both NASA and DOD programs as well as on Douglas commercial aircraft programs.

As demonstrated during the Space Tug Phase A Systems Study, the MDAC management philosophy emphasizes "cost planning." This planning, which will continue throughout all phases of program definition and beyond, will result in cost awareness/cost avoidance attitudes that are essential to effective project cost control. This cost planning is not limited to just the prime contractor role, but will extend through the working relationships to the Government and to the suppliers to establish clear-cut cost objectives and the management plans appropriate for achieving these objectives.

MDAC's cost-awareness/cost avoidance philosophy on the Space Tug emphasizes the identification of and the avoidance of all unnecessary costs. This will call for close contractor/Government working relationships and teamwork to define and manage to effective project requirements. The net effect of the application of this philosophy is to develop the Space Tug with only the necessary equipment, material, and labor, and hence at lower costs.

Highlights of the MDAC low-cost management approach on Space Tug include:

- Develop (in concert with the customer) well-defined mission performance parameters and cost objectives early in DDT&E.
- Assign highly capable personnel with applicable experience.
- Develop well-defined program plans based upon essential technical and management requirements to accomplish the mission. These plans will be brief and concise and directive in nature to provide clear management direction and assessment without excessive detail.
- Provide closely coupled contractor/Government working relationships including collocation of counterparts and task-sharing where effective.

- Develop specific contractual clauses that provide motivation to both the contractor and Government to achieve the lowest cost consistent with excellence of performance and tight schedule requirements.
- Operate critical change control under strict criteria (is it functionally necessary--is it cost-effective) for accept/reject decision.
- Apply management systems responsive to the needs of the contractor and Government and provide timely visibility into potential problem areas to avoid vulnerability to unplanned cost or schedule delays.
- Procure "buy" items, particularly off-the-shelf material and subsystems/components, from lowest-cost, technically capable suppliers.

Features of several of the more crucial management systems are presented below:

- Performance Measurement System (PMS)
  The MDAC PMS is an on-line approved system currently in use on the Air Force ACE program, the Army SAFEGUARD/Spartan and Site Defense programs, and the Navy Harpoon program. Out experiences show that a low-cost and effective PMS requires a realistic WBS structure, ability to selectively apply BCWS/BCWP and variance analyses, ability to adjust the levels of reporting and control to the magnitude of the cost risk represented by the WBS element, and to provide management reports at meaningful time intervals.
- Cost-Per-Flight (CPF) Management Controls
  CPF controls have been developed that are closely integrated with the PMS and the change control system. Based upon MDAC's life-cycle-cost-modeling technology, CPF provides cost goals (targets) throughout the WBS. CPF provides continuing predictive capability for total cost and CPF, impact assessment, and variance projections against lower-level WBS element cost targets as well as total project cost. Multi-discipli specialists work closely together to develop the cost estimates leading to the CPF targets. The task and functional managers are fully account able for successful attainment of CPF goals including development of the options and trade analyses necessary to recover should unfavorable variances appear. One of the keys to achieving low-cost objectives is

- Configuration and Change Management (CM)

  The goal of CM is to effectively define contract item configuration and to manage change. On the Space Tug, it is imperative that once a configuration is defined that strict criteria be established by which a proposed change can be evaluated and accepted/rejected rapidly and effectively. The configuration control board chaired by the program manager will use the CPF analysis to know the impact of changes against the CPF targets and the cost budgets. There is a corollary to the use of strict change criteria, which implies that to avoid unnecessary costs the mission requirements be well defined and that the design team design it right the first time to minimize changes.

- Information Management (IM)

  The most effective as well as lowest-cost IM system is one that makes maximum use of informal direct communication between designated contractor/Government counterparts for daily decision-making. This informal interchange is backed up by the formal contractual reporting system which provides documentation of the key data and decision/action items for historical reference. The contracted data procurement document and data requirements list will make maximum use of internal data wherever possible. In addition, MDAC's accessioning and deferred delivery methods will offer the customer up-to-date information on available internal documentation while minimizing the need for routine submission of data.

- Procurement Management

  MDAC's approach to make-or-buy, source selection, and procurement is to make use of existing proven industry capabilities, while maintaining focus on the CPF targets. CPF targets are passed on to subcontractors and suppliers with appropriate contract incentives. Supplier reports are integrated into our PMS and CPF project reviews with a minimum of reprocessing. In accord with our internal information management system, the customer will have direct access to subcontractor/supplier data.

- Engineering Management

  MDAC's design team has extensive and successful cryogenic launch vehicle experience. A single organization will perform analyses, integration, and design tasks supported by functional specialists, as required (tooling, manufacturing, quality, test, logistics, etc.), who are involved from project inception. Supporting this multi-discip team approach is the recommendation for collocating contractor/customer/supplier representatives to encourage face-to-face daily dia-logue. Cost-per-flight targets are assigned down to the lowest practi-cal level of the WBS and the design team will have specific design-to-cost training. As the design concept evolves, senior engineers will be part of the team who will review the mission requirements, the design requirements, the detailed specifications, and the design drawings to ensure a thorough evaluation of alternatives to emphasize low-life-cycle costs, standard parts, and off-the-shelf hardware. Critical technical performance parameters, e.g., CPF, are selected for status reporting to provide most meaningful technical progress assessment. Parameters are tracked by time-dependent trend data or single-point events and are measured by analysis or test with variances reported in time for corrective action with minimum cost/schedule impact. In addition to the above, the Engineering and the Manufacturing releases are closely coordinated (jointly signed off) before release to ensure full understanding and communication of each others requirements and intentions.

In summary, application of MDAC's cost awareness/cost avoidance philosophy will enable Space Tug to avoid unnecessary material and labor costs. We will:

A. Understand the essential mission and program requirements, specifically:
   1. Technical
   2. Management
   3. Cost

B. Design and manage to meet the essential life-cycle requirements and the CPF targets.

C. Test to verify design but minimize test hardware requirements and

.5 SUPPORTING RESEARCH AND TECHNOLOGY SUMMARY (SR&T)

ecause of the emphasis on performance and total program cost effectiveness, ption 2 requires some $15+ million in supporting research and technology. his program element is summarized in Table 5-11.

he first technology requirement identified stemmed from basic safety require- ents rather than program objectives. The proposed use of graphite epoxy oneycomb for performance reasons created the second technology requirement. asic data is needed in the thermal control area to establish performance and abrication techniques. In the G&C area, star tracker self-check and IMU self- alibration are needed to reduce maintenance costs. Laser radar rendezvous/ ocking techniques need substantial advancement before final definition for the ug. Performance is the primary result of improving fuel cell specifics.

he SR&T for the option represents just over 5 percent of total program DDT&E.

Table 5-11

SR&T SUMMARY--OPTION 2

WBS Element/Option	Technology Requirement	Cost ($M)	Time (Years)	Required Start Time
320-03				
Vehicle main stage	Develop potential hazard/failure techniques	0.75	1.5	CY 1/79
320-03-01				
Structures				
Body structure	Develop material properties and manufacturing process for thin-skin bonding	1.50	1.5	1/79
320-03-02				
Thermal control multi-layer insulation and purge bag	Establish thermal performance, material properties and purge bag material, fabrication, and operation techniques	0.18	1.5	2/79
320-03-03				
Avionics - GN&C	Increase star tracker self-check capability	3.00	1.5	1/79
	Add IMU self-calibration capability	2.00	1.5	1/79
Rendezvous/docking	Develop laser radar rendezvous/docking techniques	5.00	2.0	7/78
Power	Reduce fuel cell weight, increase efficiency, life	3.00	1.0	7/79
	Total	15.44		

5 RISK ASSESSMENT SUMMARY, OPTION 2

The Space Tug project is in the early stages of program definition (Phase A). We are confident that as the hardware, software, and programmatics are defined, the risk values identified will diminish significantly. Therefore, we assess Program Option 2 as a moderately-low-risk program.

On a scale of 0 to 10 (i.e., low to high risk), the average life-cycle risk values for Option 2 are 2.4 for cost, 2.3 for schedule, and 3.2 for technical performance. Risk Assessment Summary is given in Table 5-12. These relatively low risk values mean that the multi-discipline team of experts, who have assessed the uncertainties in accomplishing the cost, schedule, and technical objectives and assigned the risk values, have a moderately high degree of confidence that all objectives will be met for every WBS element in every phase of the project. Their collective judgments are based on the following:

A. Specifications on similar hardware and software items are available.

B. The hardware and software subsystems and components are well within the state of the art and at the minimum, prototype items have been produced (in many cases, off-the-shelf hardware is selected).

C. The ground rules and assumptions for estimating were generally adequate although subject to some question.

D. The data have generally been obtained from reliable sources. A full description of our risk assessment methodology and the detailed data sheets are presented in Section 9 of Volume 8.

In the risk assessment data sheets (Table 5-13), a narrative assessment is provided for all cost, schedule, and technical risk values of 5 or greater. It is significant that most of the moderate-to-high risk values are due to the preliminary or incomplete nature of the information available and are not due to technical or capability uncertainties. Therefore, as the program is further defined, we can expect a corresponding decrease in all risk values.

Table 5-12

RISK ASSESSMENT SUMMARY, OPTION 2

Risk Values (0 = Low; 10 = High Risk)

Project Phase	Risk Area		
	Cost	Schedule	Technical
DDT&E	3.0	2.3	3.6
Prod	2.2	2.1	3.1
Opns	2.1	2.6	2.8
Average Life-Cycle	2.4	2.3	3.2

Table 5-13

RISK ASSESSMENT DATA SHEET

WBS Element	Risk Values 0 = Low; 10 = High: Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
1 oject Management	3	1	1	
2 stems Engr and Integration	3	1	1	
3 hicle Main Stage				
-01 Structures	2	3	4	
-02 Thermal Control	2	3	4	
-03 Avionics	3	3	7	Laser docking/advanced fuel cell/solid power dist (tech)
-04 Propulsion	2	2	4	
-05 Orbiter Interface	5	1	6	Prelim spec definition (cost); Prelim abort data and analysis (tech)
-06 Drop Tanks	N/A	N/A	N/A	
-07 Final Assy and C/O	2	3	6	Pressure/chemical/heat hazards (tech)
icle Auxiliary Stage	5	GFE	1	Manufacturing start-up on Poseidon; questionable (cost)

Table 5-13

RISK ASSESSMENT DATA SHEET (Continued)

Program Option 2, DDT&E Phase

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
-5 Logistics	3	3	1	
-06 Facilities	5	3	1	Prelim information only (cost)
-07 Ground Support Equipment	3	3	7	Prelim definition of interfaces (tech)
-08 Vehicle Test	3	3	5	Prelim information ground test (tech)
-09 Launch Opns - WTR	-	-	-	
-10 Launch Opns - ETR	-	-	-	
-11 Flight Opns - WTR	2	3	3	
-12 Flight Opns - ETR	2	3	3	
-13 Refurb and Integration - WTR	-	-	-	
-14 Refurb and Integration - ETR	-	-	-	
Total Score	45	35	54	
Maximum Score Possible	150	150	150	

Table 5-1

RISK ASSESSMENT DATA SHEET (CONTINUED)

Program Option 2, Prod Phase
Page 1 of 2

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
0-01 Project Management	2	1	1	
0-02 Systems Engr and Integration	2	1	1	
0-03 Vehicle Main Stage				
-01 Structures	2	3	8	Thin graphite epoxy face sheets, honeycomb and bond techniques not state of the art (tech)
-02 Thermal Control	2	3	3	
-03 Avionics	3	3	5	Prelim C/O requirements (tech)
-04 Propulsion	2	2	2	
-05 Orbiter	3	1	5	Prelim spec definition (tech)
-06 Drop Tanks	N/A	N/A	N/A	
-07 Final Assy and C/O	2	3	6	Pressure/chemical/heat hazards (tech)
0-04 Vehicle Auxiliary Stage	5	GFE	1	Manufacture start-up on Poseidon. questionable

Table 5-13

RISK ASSESSMENT DATA SHEET (CONTINUED)

WBS Element	Risk Values 0 = Low; 10 - High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
05 ogistics	2	3	1	
06 acilities	1	3	1	
07 round Support Equipment	1	2	3	
08 ehicle Test	-	-	-	
09 aunch Opns - WTR	-	-	-	
10 aunch Opns - ETR	-	-	-	
11 light Opns - WTR	-	-	-	
12 light Opns - ETR	-	-	-	
13 furb and Integration - WTR	-	-	-	
14 furb and Integration - ETR	-	-	-	
Total Score	27	25	37	
Maximum Score Possible	12.0	12.0	12.0	
Risk Value (0-10 Scale)	[illegible]	[illegible]	[illegible]	

Table 5-13

RISK ASSESSMENT DATA SHEET (Continued)

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
01 Project Management	-	-	-	
02 Systems Engr and Integration	-	-	-	
03 Vehicle Main Stage				
-01 Structures	1	3	1	
-02 Thermal Control	1	3	4	
-03 Avionics	1	3	4	
-04 Propulsion	1	2	2	
-05 Orbiter Interface	1	1	1	
-06 Drop Tanks	N/A	N/A	N/A	
-07 Final Assy and C/O	N/A	N/A	N/A	
04 Vehicle Auxiliary Stage	1	GFE	2	

Table 5-13

RISK ASSESSMENT DATA SHEET (Continued)

Program Option 2, Opns Phase
Page 2 of 2

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
05 ogistics	2	3	1	
06 acilities	3	3	1	
07 round Support Equipment	2	3	4	
08 ehicle Test	-	-	-	
09 aunch Opns - WTR	3	3	4	
10 aunch Opns - ETR	3	3	4	
11 light Opns - WTR	3	3	4	
12 light Opns - ETR	3	3	4	
13 efurb and Integration - WTR	3	3	3	
14 efurb and Integration - ETR	3	3	3	
Total Score	31	39	42	
Maximum Score Possible	150	150	150	
Risk Value (0-10 scale)	2.1	2.6	2.3	

Section 6

SENSITIVITY STUDIES

6.1 TWO-YEAR-EARLIER IOC

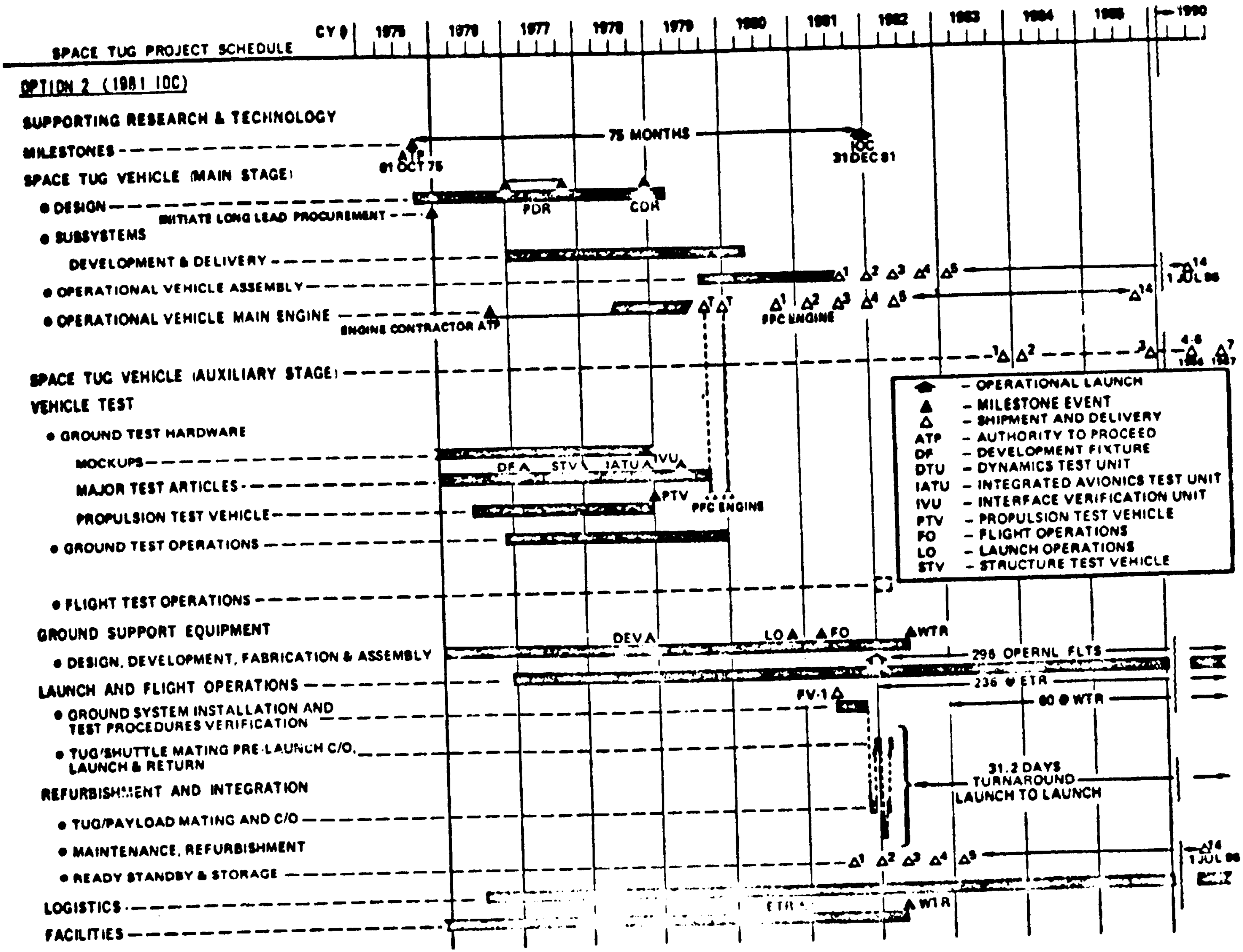
The objective of this analysis was to determine the programmatic sensitivity of Option 2 to a two-year-earlier IOC, December 31, 1981 in lieu of the baseline December 31, 1983. Impacts on DDT&E, production, and operations costs and funding requirements were determined. Primary goals were to evaluate techniques for reducing the peak-year funding requirements without excessive impact on funding requirements in the early program years (FY 1976 through 1980). These early years represent the critical range of Shuttle program ling impacts on Tug funding availability.

For the early IOC analysis, it was assumed that the baseline ATP (June 1979) would be moved to October 1975, giving a 20-month increase in the development time from ATP to IOC. By moving the IOC two years earlier, Option 2 is capable of performing 74 additional flights (19 in 1982, 35 in 1983, and 20 in 1984). This results in a cost increase of $57 million in the operations phase.

The additional 20 flights in 1984 resulting from the earlier IOC were deleted from the baseline option flight schedule because of programmatic considerations to provide a gradual buildup in operational flight activity the first two years after IOC. The 20 flights include two expendable-mode flights. Because of this, the vehicle fleet size of 12 for the baseline Option 2 must be increased to 14 for the earlier IOC. The increase in production costs for the two added vehicles is offset, however, by the stretchout of vehicle duction.

Figure 6-1 presents the planned project summary schedule for the IOC shift and reflects the lengthened activity spans and milestone adjustments. Stretch-out of the manufacturing operations results in a vehicle delivery rate of

SPACE TUG PROJECT SCHEDULE



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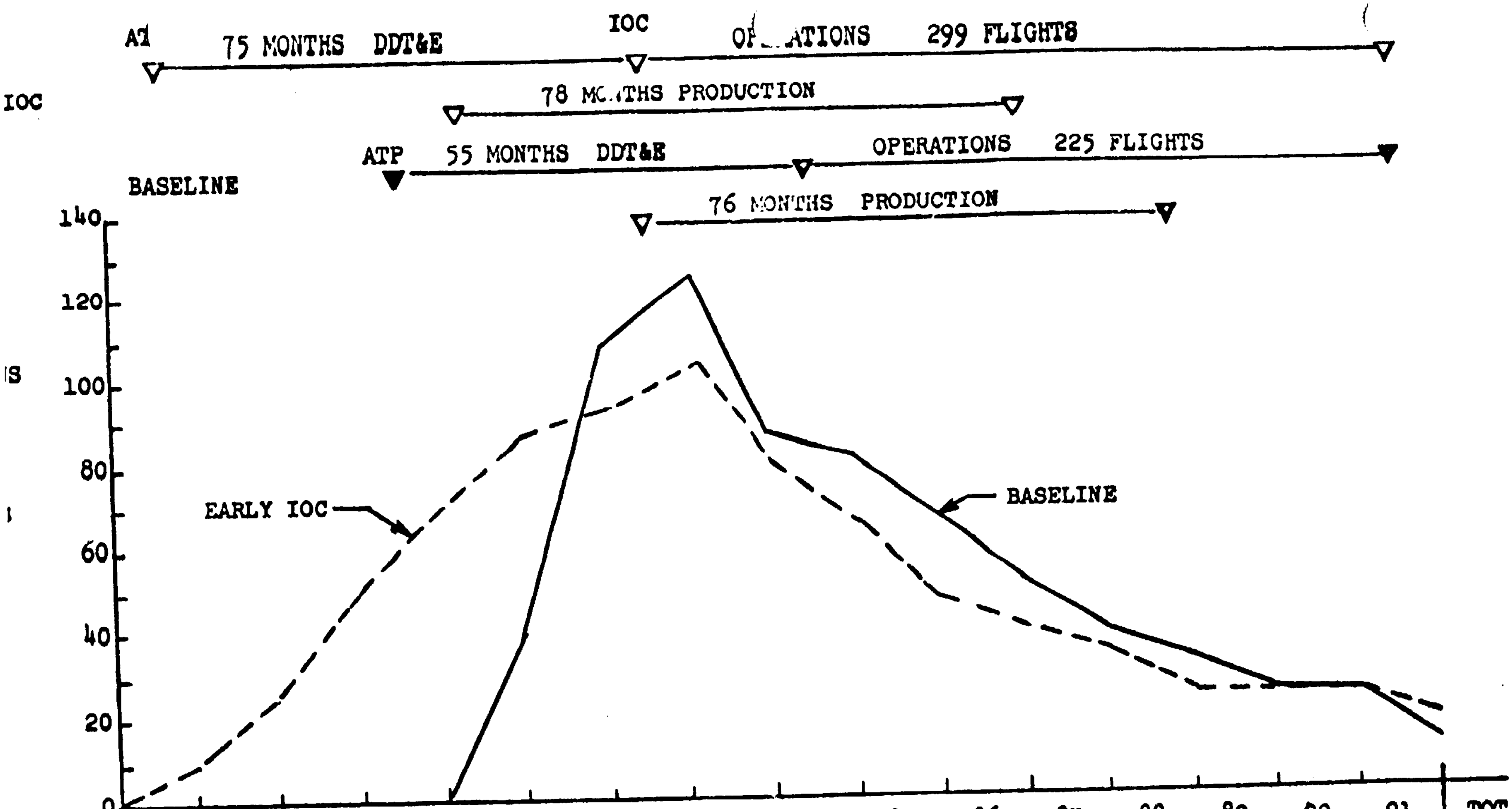
gure 6-2 presents a summary of the earlier IOC impact on total project costs and funding in comparison to the baseline Option 2. Peak annual funding is reduced to $104 million in FY 1982 for a net reduction of $20 million. Total program cost increases $105 million to $789 million, because of additional DDT&E costs (+$54 million) and operations costs (+$57 million) due to more flights. These are offset partially by a lower production cost (-$6 million) due to more optimum shift utilization. Table 6-1 provides a comparative tabulation of costs and funding by project phase. Supporting data and a detailed discussion of the cost and funding considerations for this option sensitivity analysis are in Volume 8, Book 2, Section 8.



FY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOT
IE					39	108	124	86	81	66	49	39	33	24	23	11	684
IOC	10	25	50	70	87	92	104	80	62	47	38	32	24	24	24	20	789
ICE	+10	+25	+50	+70	+48	- 16	-20	-6	-19	-19	-11	-7	-9	-	+1	+9	+105

6-2. Two-Year-Early IOC Impact on Total Project Funding, Annual Funding – Option 2

Table 6-1

2 YEAR IOC DELAY - IMPACT ON TOTAL PROJECT FUNDING/COST, OPTION 2

WBS LEVEL 3 - TOTAL SPACE TUG PROJECT

ANNUAL FUNDING - TABULAR

T FY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTALS
IE																	
:					39	102	101	43	14	1							299
CTION						7	24	44	50	41	25	15	9				215
TIONS									17	24	24	24	24	24	23	11	170
OTAL					39	108	124	86	81	66	49	39	33	24	23	11	684
RLY IOC																	
	10	25	50	70	80	70	48										353
TION					7	22	41	56	38	23	14	8					209
IONS							15	24	24	24	24	24	24	24	24	20	227
TAL	10	25	50	70	87	92	104	80	62	47	38	32	24	24	24	20	789

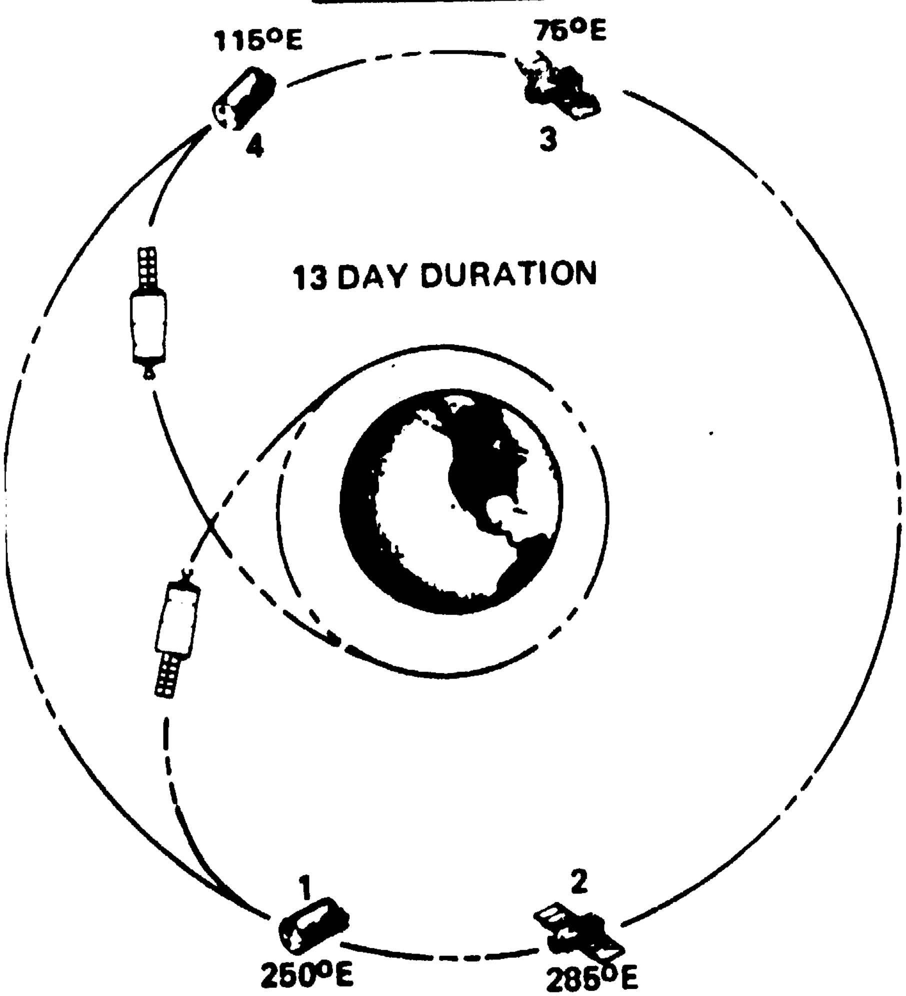
6.2 13-DAY MISSION (ON-ORBIT SERVICING) SUMMARY

sensitivity study was performed to determine the impact on the Option 2 vehicle of extending its mission duration from 6 to 13 days. The profile used in this evaluation was a 13-day mission during which four geosynchronous satellites were serviced at different longitudinal positions. Two servicing modes were evaluated. For Service Module I, the Tug starts the mission with the maximum payload service replacement units (SRU's) and service unit and drops off an equal amount to each of four satellites. The Tug returns with only the 500-lb service unit. Service Mode II carries a constant payload throughout the mission with equal payload up and down. Details of the required mission velocities and timelines are discussed in Volume 5.

This study was conducted to determine the payload capability of the Option 2 Tug for performing the 13-day service mission. This was accomplished by investigating the various subsystems to determine what changes may be required to perform the mission beyond the basic six days. Subsystems which involve on-orbit consumables such as ACPS and power were resized. During the analysis, the mission success probability goal of 0.97 was relaxed, per customer directive.

The results of the study indicated that the Tug could deploy a total of 4,150 lb for the Service Mode 1 mission (Figure 6-3). Based on a 500-lb service unit weight, 3,650 lb is available for the SRU's (about 910 lb per satellite). For Service Mode II, the Tug can carry 1,750 lb round trip, leaving a net of 1,250 lb for the SRU's (about 310 lb per satellite). The impact of the 13-day design on the nominal six-day vehicle performance is a payload loss of 568, 362, and 221 lb for the deployment, retrieval, and round-trip mission, respectively. A review of the mission capture analysis for the Option 2 vehicle indicated that these reductions would have no impact on the number of Tug flights or fleet size. Since the number of servicing missions was not specified, the impact of this mission on the program could not be assessed. The only operational impact assessed was for flight generation which resulted in an increase in DDT&E costs of about $2 million and operational costs of about $200,000 per flight. No subsystem changes were required other than to increase the ACPS and fuel cell tankage. Costs of these changes were insignificant.

MISSION



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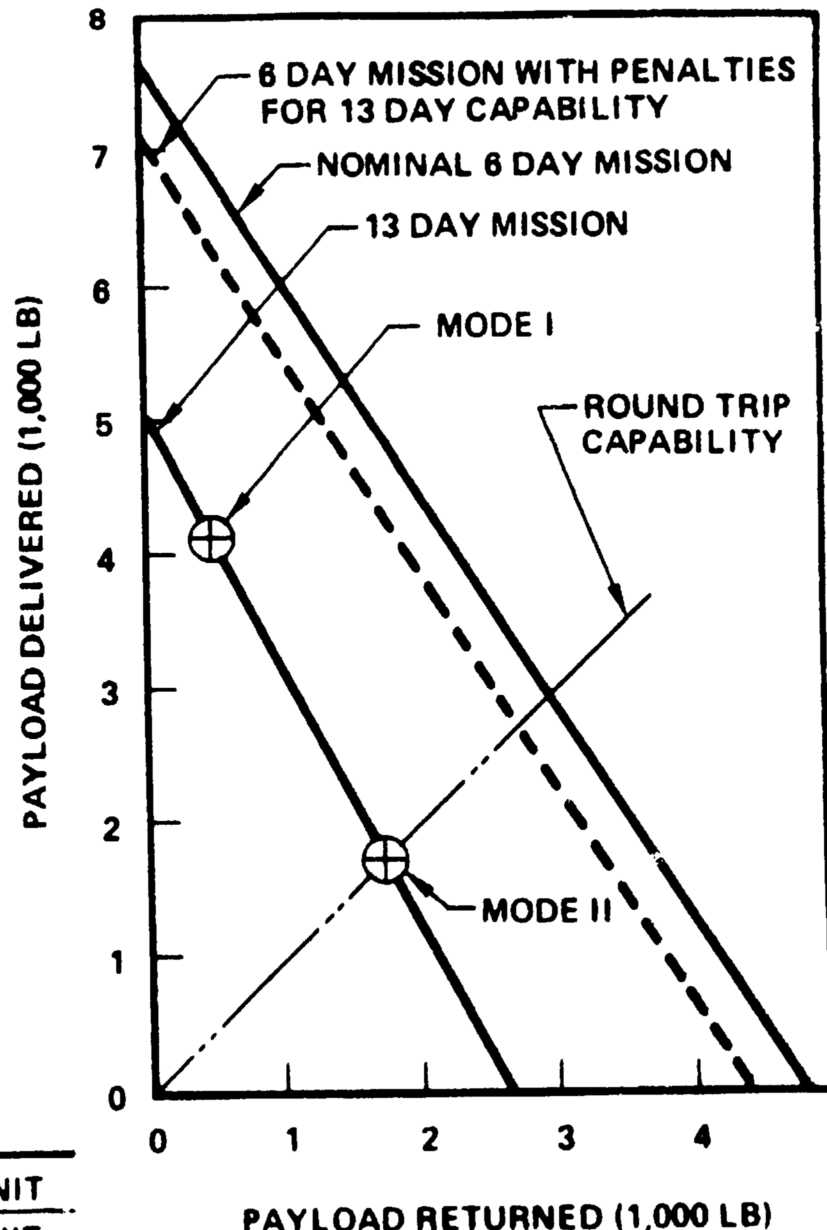


	MODE	MODE II
·ART	SRU'S AND SERVICE UNIT	NEW SRU'S AND SERVICE UNIT
TURN	SERVICE UNIT	OLD SRU'S AND SERVICE UNIT

ı 6-3. Extended Mission Duration Sensitivity – Option 2

The overall mission success probability of the 13-day servicing mission was estimated to be about 0.967.

A more detailed discussion of the 13-day sensitivity study is presented in Volume 5.

6.3 ADVANCED ENGINE EVALUATION SUMMARY

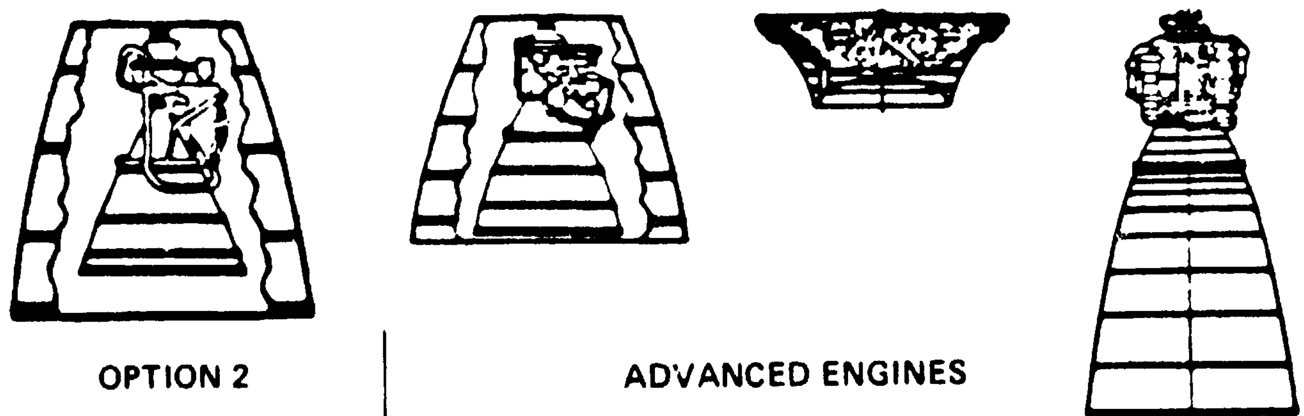
A sensitivity study was accomplished to determine the overall program impact when the Option 2 Category IIA RL10 main engine is replaced with an advanced engine candidate; i.e., Category IV RL10, advanced space engine, or the Aero With the exception of the Aerospike, the effects are primarily engine-relate engine DDT&E cost, weight, and specific impulse. The Aerospike engine provid maximum Tug performance at an engine mixture ratio of 5 to 1, while the othe maximize Tug performance at an engine mixture ratio of 6 to 1. Therefore, a using an Aerospike engine would have different tank sizes than a Tug using t engine candidates. The engine characteristics are shown in Figure 6-4.

When all of the related effects are considered and the overall program impac are evaluated, the results are as shown in Figure 6-5. This figure shows th the Tug performance increases by 10 to 20 percent, but for the mission model used, the number of flights does not change significantly and the fleet size does not change at all. The figure also shows that the total program cost increases with the advanced engines, due primarily to DDT&E cost (mostly due the main engine).

Therefore, this evaluation indicates that the advanced engines can satisfy t specified mission model without reducing the total Tug program cost. Howeve if future mission models indicate a need for increased payload capability, t Option 2 Tug is capable of accepting an advanced engine without major impact on the structure.

6.4 SENSITIVITY STUDY SUMMARY

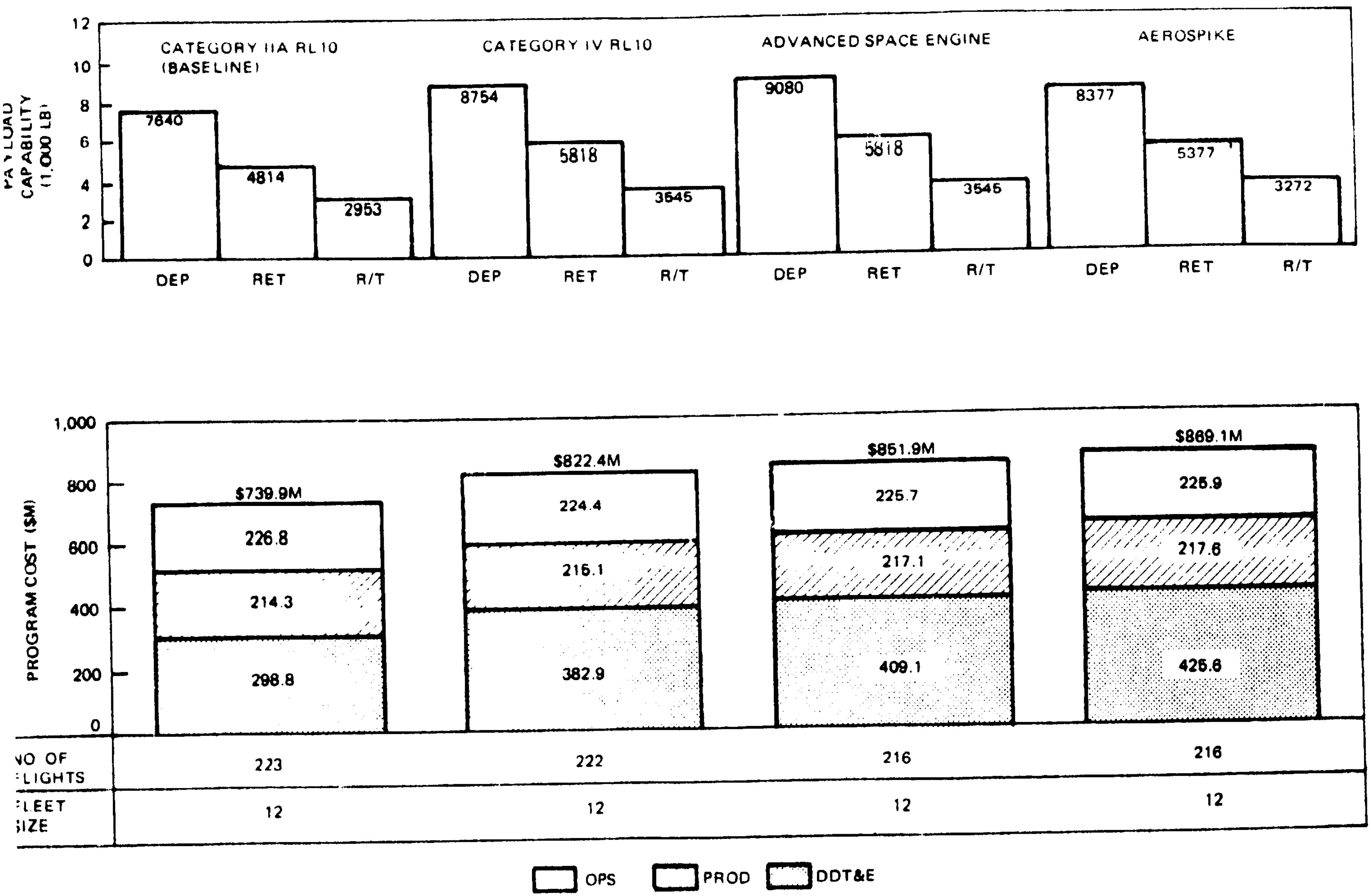
The balance of the sensitivity studies which are summarized in Table 6-2 are discussed in detail in Volume 5.



	OPTION 2	ADVANCED ENGINES		
	CAT. IIA RL 10	CAT. IV RL10	AEROSPIKE	ADVANCE SPACE ENGINE (ASE)
THRUST (LB)	15 K	15K	15K	15K
I_{SP} (SEC)	459	470	468	470
MIXTURE RATIO	6	6	5	6
WEIGHT (LB)	476	424	280	270
LENGTH (IN.)	70/127	57/114	20	88
DDT&E COST ($ M)	50*	119	140	154

* WITHOUT PUMPED IDLE

Figure 6-4. Advanced Engine Characteristics



...re 6-5. Advanced Engine Evaluation Program Option 2

SENSITIVITY RESULTS SUMM —OPTION 2

ensitivity Area	Reference	Impact Delta (Reference) Cost ($ Millions) Tech	DDT&E	First Unit	Total Opn	Veh Design Inert Wt (lb)	Payload Del Wt (lb)	Dev Risk	Critical Tech Areas
nomy	Level III								
vel IV		0	-2.89	0	5.57	- 2	+5.4	None	None
vel II			16.11	0.79	0.24	204	-5.49	Medium	Auto nav and mission plan
vel I			12.92	0.79	-0.11	204	-5.49	Low to med	Auto nav
Reliability	0.97/168 hour								
hr/Retrieval		0	0	-0.2	---	10	-27	None	None
hr/Deployment		0	-3.40	-0.66	---	36	-97	None	None
load Command, rol, and Checkout	W/O		3.48	0.72	---	+73	-197	Medium	Design complexity
gn Life (>100)	20 missions	0	0	0	0	0	0	None	None
-Stabilized Payload	No requirement	0	0	0	0	0	0	---	---
Day Mission	7 day	0	0	0	---	+73	-197	None	None

END

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